Palgrave Entry on "Growth Accounting," by Francesco Caselli

Growth accounting consists of a set of calculations resulting in a measure of output growth, a measure of input growth, and their difference, most commonly referred to as total factor productivity (TFP) growth. It can be performed at the level of the plant, firm, industry, or aggregate economy.

Current growth-accounting practice tends to rely on the theoretical construct of the production function both as a guide for measurement and as a source of interpretation of the results. Aside from the existence of a production function linking inputs and outputs, the main assumption is that factors of production are rewarded by their marginal product. In continuous time, this permits a representation of output growth as a weighted sum of the growth rates of the inputs, and an additional term that captures shifts over time in the production function. The weights for the input growth rates are the respective shares in total input payments. Since data on the growth of output and individual input quantities cover discrete periods of time, a discrete-time approximation to the weights is required. Current practice tends to use simple averages of the input shares at the beginning and the end of each period. In the special case that the production function is of the translogarithmic form this procedure actually results in an exact decomposition. Otherwise it can be interpreted as a second-order approximation.

It is customary to group inputs into broad categories. When output is measured as value-added the broad categories are labor and capital. When output is total production one has to add materials, occasionally further broken down with further entries for energy and services (giving rise to the so-called KLEMS accounting framework). This kind of grouping allows one to speak of, e.g., the "contribution of labor (capital, materials) to output growth." However, this grouping masks an enormous heterogeneity of the underlying inputs. This heterogeneity is the source of a large share of the measurement problems in growth accounting. These problems are most severe in the measurement of the growth of capital input.

Capital inputs are heterogeneous within vintages (e.g. tractors v. personal computers) and across vintages (computers produced in 2006 v computers produced in 2007). Heterogeneity within vintages is best addressed by having as fine a disaggregation of capital types as the data will allow. The most important data constraint on disaggregation of capital types occurs in the construction of type-specific shares in total capital income, as these requires type-specific estimates of rental rates, and these in turn require type-specific estimates of depreciation rates, capital gains, and tax treatment. Heterogeneity across vintages, also known as embodied technical change, or quality change, poses even more difficult problems. Most practitioners' ideal solution to this problem is to put the measurement of the stocks of different types of capital on a constant-quality basis, by applying appropriate deflators reflecting quality change to the corresponding investment series. However the availability and/or accuracy of such deflators, whose construction generally requires hedonic methods, is currently limited for most countries, industries, and capital types. As a result there is a presumption that the growth rate of (the efficiency units embodied in) the capital stock is often understated.

Construction of indices of labor input growth have conceptually similar problems. However aggregation across types (e.g. female, white, high-school graduates, of age 40-to-45 v. male, black, college graduate of age 35-to-40) is simpler as average rental rates (i.e. hourly wages) for reasonably fine categories are reasonably well observed (while in the case of capital goods they must be estimated). The vintage problem is typically bypassed by assuming that there is no quality change within narrowly-defined categories.

Another difficult problem is how to turn the growth in input stocks into growth in the flow of input services, i.e. how to account for variation in the rate of utilization of labor and capital. Measuring labor in hours is helpful, but an issue of utilization still remains if effort per hour is not constant, as is likely. For capital, various adjustments based on proxies for utilization have been proposed, a classic one being a measure of electricity consumption. But this approach to the problem of measuring utilization creates a deeper problem of interpretation, or at least a conflict with the estimate of rental rates. This is because the latter are constructed in a way that assumes them to be invariant to the rate of utilization. But in this case the opportunity cost of setting the utilization rate to 100% all the time is nil, and there should be no variation in utilization. Some more systematic adjustment to the theoretical framework, such as endogenous depreciation or limited opportunity for substitution between capital and other inputs, are therefore required to fully solve the measurement and interpretation challenges posed by variable utilization.

At the plant, firm, and industry levels a choice can be made between accounting for total production or value added. The total production approach is attractive, because after all it is total production that "comes out" of the production process. Furthermore, the conditions for existence of a well-defined production function for total output are far less stringent than the conditions for existence of a function linking valued added to capital and labor inputs. On the other hand, the results of growth-accounting exercises based on total output are very sensitive to the degree of vertical integration, and this causes severe problems of interpretation.

At the country level value added is obviously the only meaningful concept of output, no matter how stringent the conditions for an aggregate valued-added function. Because of the well-known shortcomings of standard measures of valued added as indicators of the "want-satisfying" capacity of the economy, some attempts have been made to augment such measures by estimates of non-market outputs, chiefly the output of the education sector. Accounting for the effects of economic activity on the natural environment is very likely the next frontier.

Among the outputs of the growth-accounting calculation the one to receive most attention is usually the difference between output and input growth. This is somewhat surprising because the interpretion of this quantity is fraught with difficulties, as underscored by the multitude of phrases used to refer to this difference: besides TFP growth, "multi-factor productivity" growth, "(Solow) residual," "measure of our ignorance," "rate of technical change," and growth in "output per unit of (total) input," among others.

What is sometimes misunderstood is the relationship between the difference and technical change. An economic unit can use additions to its capital and labor either to directly produce more output, or to devise ways to rearrange the existing capital and labor so as to produce more (constant-quality units of) output, the latter being the definition of Research and Development (R&D). If it does so by equating the marginal products of labor and capital between direct production of output and indirect production of output through R&D, the extra output produced thanks to R&D will be fully "accounted for" by the measured growth in capital and labor inputs. Hence, TFP growth does not really measure technical change as this term is commonly understood. Furthermore, failures of TFP growth to accelerate in periods/industries/firms experiencing increases in R&D spending do not need to be puzzling.

For the same reasons TFP growth can be identified neither with disembodied nor with embodied technical change. Embodied technical change in capital-using industries is a reflection of disembodied technical change in capital-producing industries, but neither need necessarily show up in the TFP numbers, as long as R&D costs have been properly accounted for.

So what does show up? Under the maintained theoretical assumptions, the cleanest interpretation – aside from weather shocks, and costless, instantaneous flashes of inspiration (if they were not instantaneous an opportunity cost of time would have to be imputed) or innovations stumbled upon by luck, none of which seems susceptible to vary much over time and space, or with government policy – is R&D externalities. If the units performing R&D fail to capture all of the social return from it, other units will experience costless growth in output per input, and this will be detected by TFP growth. Under this interpretation, a link may indeed be found between R&D and TFP growth, and if so it would be possible to use the framework to advocate policies to encourage R&D. Other forms of externalities may also give rise to positive TFP growth.

But TFP being a residual, it also picks up, as all residuals, errors of specification and measurement. We have already discussed mismeasured input growth, chiefly in terms of incomplete adjustment for quality change. A failure to account for quality change in output will push TFP growth in the opposite direction. Note that mismeasured quality change in capital results in lower TFP growth in capital-producing industries, higher TFP growth in capital-using industries, and somewhat ambiguous effects on TFP at the aggregate level, though the net effect is usually deemed to be positive.

Many economies are likely to be characterized by frictions to the efficient allocation of resources among economic units, implying that marginal products of homogeneous inputs are not equalized. In these cases improvements in the allocation of resources will also result in positive TFP growth.

It is impossible to overestimate the interest that growth-accounting calculations have elicited. There must very few industries and countries for which some kind of input-output data exists and nobody has used it to perform a growth accounting exercise. Indeed, several national statistical agencies explicitly include the output of growth-accounting calculations, including TFP growth, into the national accounts.

I am unable to provide here an overview of this immense body of work, and the reader will have to refer to the country-industry-period of interest on a case by case basis. However there are a couple of broad lessons that can be distilled here. First, over the medium-to-long term, the residual accounts for a relatively minor portion of overall growth in output. For example for the US it is possible to explain about two-thirds of growth in (market) output per worker over the post-war period by changes in the quality and quantity of inputs. For countries experiencing exceptionally high growth rates, such as the Asian Tigers between 1960 and 1990, this share is even higher. To the extent that the residual picks up measurement and specification errors, this is tantamount to saying that the performance of the growth-accounting methodology is very good by the standards of empirical work in economics. This interpretation is reinforced by the fact that, again by and large, the role of the residual tends to be systematically smaller in studies deploying better quality data.

Over shorter horizons, however, TFP growth is harder to underplay. For example a slowdown in TFP growth "accounts" for a large fraction of the slowdown in output growth observed between the mid-70s and the mid-90s. Not coincidentally, the root causes of that slowdown remain as mysterious as ever.

While growth-accounting calculations can be performed at various levels of aggregation, and their interpretation is perhaps easier the smaller the unit of analysis, the origins of growth accounting are macroeconomic. The earliest growth-accounting exercises [Stigler (1947), Schmookler (1952), Abramowitz (1956), the latter also coining the expression "measure of our ignorance"] were a direct by-product of the development of US aggregate national account data. One exception was agriculture, for which early growth-accounting experiments date to 1948 (Barton and Cooper) and 1951 (Kendrick and Jones). Kendrick (1956, 1961) compiled the first large scale growth-accounting calculations broken down by many industries. He also introduced the phrase "total factor productivity."

Solow (1957) laid out the theoretical foundations of growth accounting [a previous contribution in this direction by Tinbergen (1942), with attendant calculations, was discovered by the English-language literature only subsequently]. Solow (1960) and Jorgenson (1966) worked out the implications of embodied technical change. Denison (1962) introduced corrections for changes in the composition of the labor force. Griliches and Jorgenson (1966) and Jorgenson and Griliches (1967) put aggregation of inputs and outputs on a solid theoretical basis, particularly by showing how to correctly estimate rental rates. They also pioneered empirical approaches to quality change and variable utilitization. This program was further refined by Christensen and Jorgenson (1969, 1970) for the aggregate economy, and Fraumeni, Gollop and Jorgenson (1987) for a broad set of industry-level calculations which has shaped the way US national accounts are now constructed, and whose methods are widely accepted to be the gold standard for the purposes of productivity measurement.

Christensen, Jorgenson, and Lau (1973) developed the translogarithmic production frontier, and Diewert (1976) showed that with translog production functions discrete-time approximations are no longer approximations. Jorgenson and Fraumeni (e.g. 1992) attempted accounting for the output of the education sector. Young (1995) performed an influential growth-accounting exercise for the East-Asian tigers.

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