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1. Learning Outcomes

After studying this module, you shall be able to:

- Understand the concept of Solow residual
- Learn about the technical change
- Identifying the source of growth in an economy
- Discuss the criticisms of Solow residual
- Understand the concept of total factor productivity
- Learn about sources of errors
- Identifying Denison's sources of growth of an economy
- Identifying Jorgenson-Griliches sources of growth of an economy
- Discuss the criticisms of Denison and Jorgenson-Griliches approach for sources of growth

2. Introduction

In economics, growth accounting is a procedure to measure the contribution of various factors to economic growth. Growth accounting refers to the breaking down the rate of growth of total output of an economy into contribution from the growth of such inputs as capital and labour and as well as technological growth. Growth accounting is also related to the sources of growth. In an economy, the rate of technological progress is indirectly compute, measured as a residual.

Robert Solow has introduced this methodology in 1957.Further the basics of growth accounting were presented in Kendrick (1961), Denison (1962), and Jorgenson and Griliches (1967) to provide an overview of this intellectual history, with stress on the development of the Solow residual. Hence, technological progress plays a vital role in the economic growth of country.

Basically, growth accounting decomposes the growth rate of an economy's total output into two part, firstly that which is due to increase in the amount of capital and labor and secondly, that which cannot be accounted for by observable changes in factor

utilization i. e. unexplained part of growth in total output is then taken to represent increases in productivity or due to technological progress. It is also known Solow residual. The residual is the difference between the growth rate of output and the measured growth rates of inputs.

In short,

Solow residual or technical progress is the residual between output growth rate and weighted growth rates of inputs.

There are following three leading economists who have measured the contribution of the residual in terms of sources of growth to the overall growth rate of the United States economy;

- Robert Solow's Sources of Growth
- Denision's Sources of Growth
- Jorgenson-Griliches Sources of Growth

In the present module, we will discuss Robert Solow's sources of growth. Denision's sources of growth and Jorgenson-Griliches sources of growth will be discuss in the next module.

3. Assumptions of Growth Accounting

- It is based on constant returns to scale (Euler's Theorem) i.e., Capital share + Labour Share = 1.
- It is based on perfect completion.
- Capital Stock is in complete homogeneity.
- The production function is linear and homogenous i. e. neoclassical production function.
- It breaks down the growth of output into the growth of the factors of production and technical change.
- This approach is based on long run period.
- Technical change is based on Hicks-neutral augmentation.

4. Growth Accounting or Solow Residual

R. Solow published a model in 1956 that representing a simplified but at the same time powerful framework for the analysis of the causes and dynamics of economic growth. After one year, in 1957, he published a paper entitled 'Technological Change and the Aggregate Production Function'. This paper indicates that growth of aggregate production is represented as a combination of the contributions of growth rates of factors of production and technological change or total factor productivity. He separates variation in output per head due to technical change from those due to changes in availability of capital per head.

R. Solow assumes technical change as disembodied, where capital as treats as homogeneous and he also assumes that the technical change are exogenous. Disembodied technical change is capital augmented in which existing capital is made more productive. Thus, the productivity depends upon the amount of capital stock not on it age.

The production function for such technical change is written as;

$$Q = F(K, L, t)$$

Q = Output

L = Labour Input

K = Capital

T = Technical Change

Taking Hick Neutral technical change as a basis, R. Solow postulated the following specification of production function;

$$Y_t = A_t . F[K_t, L_t] \text{----------} \quad \text{(i)}$$

Where, Y_t = Aggregate production/ Total income

K_t = Stock of Physical Capital used in production

L_t = Amount of labour input

A_t = Level of technology

Equation (i) can be transformed as;

$$\frac{Y\prime_t}{Y_t} = \frac{A\prime_t}{A_t} + a_t \frac{K\prime_t}{K_t} + b_t \frac{L\prime_t}{L_t} \quad \text{---------- (ii)}$$

$$a_t + b_t = 1$$

The shares of capital and labour costs in total costs are a_t and b_t respectively. So the of shares is equal to one.

The equation (ii) can be written as;

$$\frac{A'_t}{A_t} = \frac{Y'_t}{Y_t} - a_t \frac{K'_t}{K_t} - b_t \frac{L'_t}{L_t}$$

i.e.

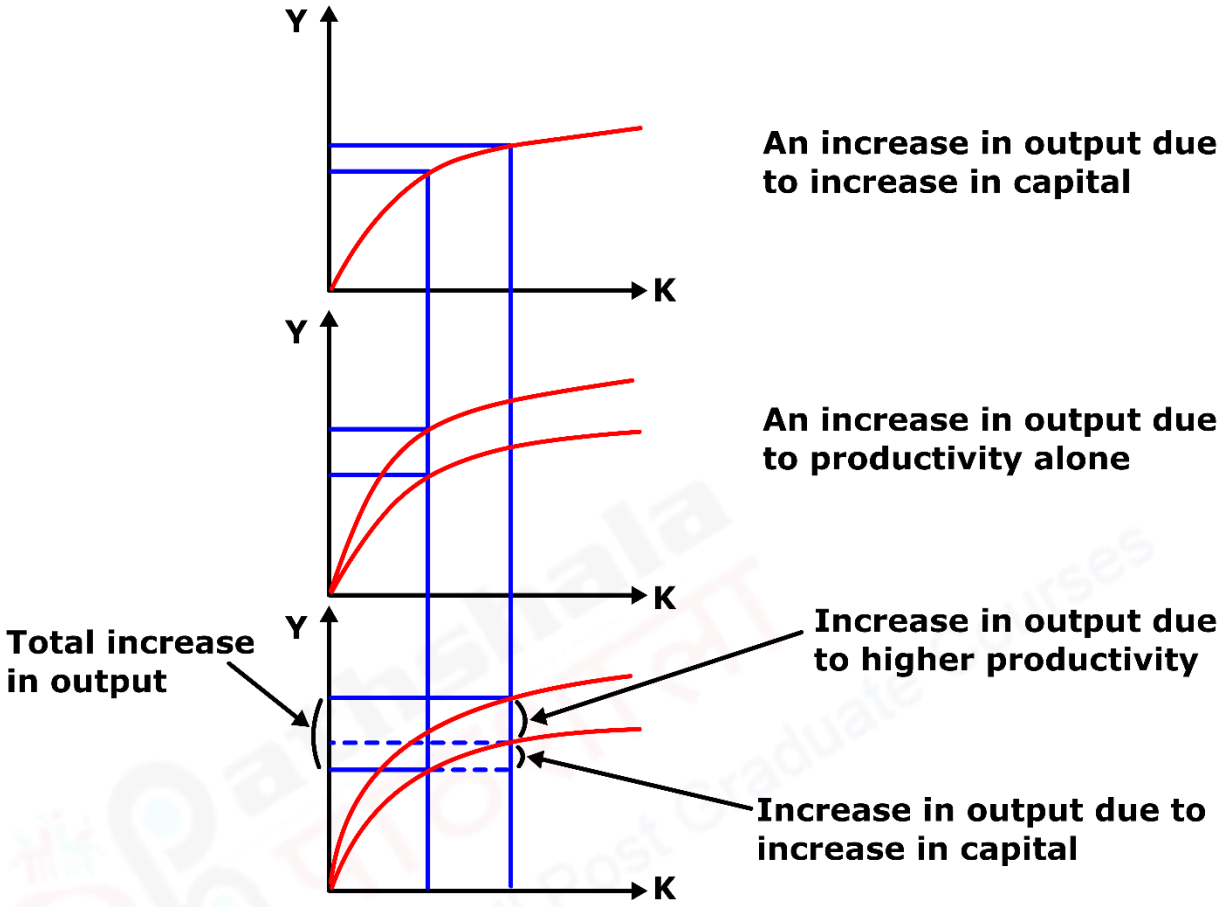
Solow Residual/ Technological Change
=
Rate of Growth in Aggregate Production
-
Growth Rate of Physical Capital and Labour Input

Empirical Results

Robert Solow proceeded to focus on rate of technical change by using data on the share of capital and labour and the rates of growth of capital per head. He stated that the contribution of the residual is obtained after calculating the contribution of capital. The residual is attributed to technical progress. He concluded that the average growth rate of output per head in United States could be attributed 12.5 per cent to increase in capital per worker and the residual 87.5 per cent to technical change during the period 1940-49.

Graphical Presentation

The latter calculation is also known as Solow residual. The diagrammatical representation of technological change is given below. The third part of diagram indicates the output growth due to higher productivity or Solow residual and due to increases in factor of production.



Examples of Solow Residual

For an example, consider Indian economy, whose total output grows at 5 per cent per annum. Assuming that there are two factors of production i. e. capital and labour. During the same period its capital stock grows at 7 per cent per annum and its labor force by 3 per cent per annum. The contribution of the growth rate of capital to output is equal to that growth rate weighted by the share of capital in total output and the contribution of labor is given by the growth rate of labor weighted by labor's share in income. The share of capital's and labour in total output are 1/3 and 2/3 respectively. This means that the portion of growth in output which is due to changes in factors is $0.07\times(1/3)+0.03\times(2/3)$ = 0.043 or 4.3 per cent per annum. This means that there is still 0.7 per cent per annum of

the growth in output that cannot be accounted for. This remainder/ residual are the increase in the productivity of factors that happened over the period, or the measure of technological progress during this period.

5. Criticism of Solow Residual

Robert Solow has been criticized for his approach of measuring the residual/ technical change on the following grounds;

- This approach is based on several unrealistic assumptions such as perfect competition, complete homogeneity of capital stock and constant returns to scale.
- Solow estimates undermine the role of investment in context to technical change in process of growth. According to Phelps, 'The results of Solow approach produced a wave of investment pessimism.'
- Solow further admitted that there are index number problems involved in the measurement of every variables in his measurement of the residual.
- This approach ignored the various components of sources of growth such as improvement in skill and quality of labour force, improvement in technological level, change in composition of inputs and output of an industry, investment in research and education and so on.
- Several economists point out that Solow emphasis the role of capital by assuming disembodied technical progress, whereas the most significant advances in technical progress requires capital embodiment. R. Solow himself admitted it in 1959.
- Abramovitz considered residual as 'a measure of our ignorance'. While according to Rosenberg, residual 'provided a wide response on the part of economists wakened, as it were from their dogmatic slumber.'

- Griliches pointed out that the residual approach is not of much use in understanding the growth process because it is based on the concept of unstable production function which is the causes of very large unexplained shifts in it.

6. Denison's Sources of Growth

Introduction

Robert Solow (1957), Denison (1962), and Jorgenson-Griliches (1967) are the leading economists of growth accounting approach. By using this approach they have discuss sources of growth or technical change by different way. Solow approach has been discussed in previous module. The present module is relating to Denision's and Jorgenson-Griliches sources of growth. Firstly, Denison approach will be discussed.

A number of studies for United States have done by Denison. He have identifies a number of sources of growth and estimates the portion of the growth rate attributable to each. He divides the sources of growth into four important categories;

I. The contribution of two factor of production i.e., labour and capital, adjusted for quality changes but not depend on technical change.
II. Advancement in knowledge, which is a true measure of total factor productivity (TFP), obtained as a residual.
III. Resource allocation improvement
IV. Economies of scale

Measurement of Sources of Growth: Empirical Explanation

In his study entitled 'The Sources of Economic Growth in the United States', he estimated the contribution of different sources with the help of Cobb-Douglas type production function. He kept all inputs i.e., labour and capital together. Denison marked an index of the stock of inputs on the basis of the base year 1929. For constructed this weighted index, he used relative share of income in the base period. In calculating the contribution of education to output, he has treated workers of different educational

categories as different inputs. Then the growth rates of the number of workers in different educational categories were aggregated into an index of the growth rate of total labour input according to their shares of total labour hours.

For index of capital, he was taken four types of capital inputs;

- Non-farm residential structures
- Other structures and equipment
- Inventories and;
- US international assets

Each types of capital was weighted by its own base year returns in the estimating its contribution to growth.

The index of the contribution of increases in output per unit of input comprised advancement in knowledge, resource shift from agriculture to industry and economies of scale

Table 1: Sources of Growth of Real National Income of the US during 1929-57

Sources of Growth	Growth Rate	Per cent of Growth Rate
A. Real National Income	2.93	100.0
B. Increase in Total Inputs	2.00	68.3
(a) Labour	1.57	53.6
(b) Capital	0.43	14.7
(c) Land	0.00	0.00
C. Increase in Output per Unit Input	0.93	31.7
(a) Advance in Knowledge	0.59	20.1

(b) Resource Shift	0.07	2.4
(c) Economies of Scale	0.34	16.6
(d) Irregular Factors	-0.07	-2.4

The above table 1 shows that the growth rate of real national income was 2.93 per cent per annum during the period 1929-57 in the United States economy. The growth rate is calculated from the real net national product at the factor cost. Out of the 2.93 per cent growth rate, 2 per cent are accounted by increase in total inputs and 0.93 per cent increase by productivity (increase in output per unit of input). Out of 2 per cent increase in inputs, 1.57 per cent is accounted by labour and 0.43 per cent by capital.

The contribution of productivity of US real income growth was 0.93 percentages. That is 32 per cent of total sources of growth. According to Denison, this is the residual factor. He divides the increases in output per unit of input into three main components i.e., advance in knowledge, resource shift from agriculture to industry and economies of scale. Thus of the 32 per cent contribution of increase in productivity is comes from advance in knowledge (20 per cent), resource shift (2.4 per cent) and economies of scale (12 per cent).

According to Denison, the contribution of education increases the quality of labour force while the advancement in knowledge is a technical change. Denison regards advancement in knowledge as the 'true residual' and education as 'guesstimated'. So far as other factors like recourse shift and economies of scale are concerned as the lower size of true residual.

Criticisms of Denison's Approach

Denison approach of sources of growth is different from Solow's approach of sources of growth. R. Solow attributes the residual to technical change on the other side Denison breaks the residual into further components. Denison attributes increases in growth to improvement in the quality of labour force as a consequence of better and more education and advancement in knowledge.

However, he has been criticized for the following weakness in his study of sources of growth;

- Economists have questioned the effect of education on earnings which is the index of quality of labour. They find the adjustment factor of 40 per cent for ability, leaving 60 per cent of differences on income differentials.
- Lundberg has criticized the use of Cobb-Douglas production function by Denison for calculating the contribution of factors of production to growth rate of national income. According to him, the specific C-D function attributes large share of labour income and low share of capital. He also points out that a static equilibrium concept like the production function is a doubtful tool for analysis the dynamics of growth.
- Denison's estimates are based on constant returns to scale, which are available after making payments to all factors according to their marginal productivity. This is unrealistic assumption.
- Denison has also been criticized for assuming 'disembodied technical' progress. In fact, this process should be 'embodied' in plant and equipment. According to J. Sandee, 'the believer of 'embodied' progress usually finds at least twice the yield deduced by the classical Cobb-Douglas disembodied trend analyst, because he consider the whole 'residual' as the result of new investment'.
- Denison does not consider joint effects of capital and technology. Rather, he treats them as separate elements and does not attribute technical progress to the extra capital.

Concluding Remarks

- Despite the above criticism, Denison has performed an extremely useful work in quantifying the contribution of increases in physical inputs i.e., education and advance of knowledge, to growth.
- His estimates of sources of growth can be accepted with some level of confidence.

- He attempts to quantify the sources of increases in output per unit of input,
- However, some of his conclusions must be considered of doubtful worth.
- The residual factor in economic growth remains the coefficient in our ignorance.

7. Jorgenson-Griliches Sources of Growth

Introduction

Jorgenson-Griliches examined a hypothesis concerning the explanation of changes in total factor productivity (TFP) in his study of sources of economic growth in the United States private domestic sector economy. According to this hypothesis, if the measurements of quantity of capital and labour are accurate then the growth in total output is mainly accounted by growth in total inputs. The differences between the rate of growth of real product (output) and real factor input is called the rate of growth of total factor productivity (TFP). In the social accounting framework, it is hypnotized that if the real product and real factor input are accurately measured then the observed growth in total factor productivity is negligible.

Jorgenson-Griliches has pointed out that there are many sources of error in system of social accounting of real product and real factor inputs. The error is frequently creeping into the measurement of movements in total factor productivity, which biases the estimates upwards. There are following four important sources of errors;

- Errors in aggregation in combining in goods (investment and consumption) and services (labour and capital)
- Errors of measurement in the prices of investment goods
- Errors from assuming that the flow of labour and capital services is proportional to stocks of capital and labour.
- Errors as a result from the aggregation of investment goods and capital services on the side and on the other side of labour services.

Measurement of Sources of Growth: Empirical Explanation

Jorgenson-Griliches have construct indices of total output and total input for United States domestic private sector economy for the period 1945-65 without correcting for error of measurement to prove their hypothesis. They have taken the US domestic private sector economy in constant prices for an initial index of total output. They have also taken the sum of labour and capital services in constand prices for construct index of total input. Labour and capital services are assumed to be proportional to stocks of labour and capital respectively. The number of persons engaged in the private domestic sector of Unites States economy is taken as stock of labour and the sum of land, plant, equipment and inventories employed in this sector is taken as stock of capital. The difference between the rate of growth of total output and total input is called the rate of growth of total factor productivity (TFP).Jorgenson-Griliches found that the average growth rate of total output was 3.49 per cent per annum during the period 1945-65 and the average growth rate of total input was 1.83 per cent per annum during the same period. Then the average growth rate of total factor productivity was 1.60 per cent per annum. Thus, the contribution of total input and total factor productivity (TFP) in total output growth was 52.4 per cent and 47.6 per cent respectively. These were the initial estimates of growth rate of total output, total input and total factor productivity.

Elimination of Errors

After these initial estimates of growth rate of total output, total input and total factor productivity, Jorgenson-Griliches eliminate the errors of aggregation and measurement. They have reached the following estimates shown in Table 2.

Table 2: Total Output, Total Input and Total Factor Productivity of US during 1945-65

Estimates	Average Annual Growth Rates (%)			Contribution of Input to Output (%)	Contribution of TFP to Output (%)
	Output	Input	TFP		
A. Initial	3.49	1.83	1.60	52.4	47.6
After Correction For;					
B. Errors of Aggregation	3.39	1.84	1.49	54.3	45.7
C. Errors in Investment Goods Prices	3.59	2.19	1.41	61.0	39.0
D. Errors in Relative Utilization	3.59	2.57	0.96	71.6	28.4
E. Errors in Aggregation of Capital Services	3.59	2.97	0.58	82.7	17.3
F. Errors in Aggregation of Labour Services	3.59	3.47	0.10	96.7	3.3

Errors of Aggregation: After elimination of error of aggregation of consumption and investment goods Jorgenson-Griliches found that the average growth rate of total output was 3.39 per cent per annum during the period 1945-65 and the average growth rate of total input after elimination of labour and capital services was 1.84 per cent per annum. Then the average growth rate of total factor productivity was 1.49 per cent per annum. Thus, the contribution of total input and total factor productivity (TFP) in total output growth after error elimination was 54.3 per cent and 45.7 per cent respectively.

Error in Investment Goods Prices: After elimination of errors of measurement of investment goods prices, the role of total factor productivity has been decline. The above table reveals that with the errors of measurement of prices of investment goods eliminated, the growth rate of total input to total output is 61 per cent per annum, leaving 39 per cent per annum due to total factor productivity.

Errors in Relative Utilization of Labour and Capital Stock: Due to eliminating the errors in the measurement of relative utilization of labour and capital stock, the growth rate

of total output, total input and total factor productivity are found 3.59 per cent, 2.57 per cent and 0.96 per cent per annum respectively. Thus, the contribution of total input and total factor productivity (TFP) in total output growth was 71.6 per cent and 28.4 per cent respectively.

Errors in Aggregation of Capital Services: When the errors in aggregation of capital services are eliminated then the growth rate of total output, total input and total factor productivity are found 3.59 per cent, 2.97 per cent and 0.58 per cent per annum respectively. With these errors eliminated total input explains 82.7 per cent of the growth in total output, leaving 17.3 per cent per annum due to total factor productivity.

Errors in Aggregation of Labour Services: When the errors in aggregation of labour services are eliminated then the growth rate of total output, total input and total factor productivity are found 3.59 per cent, 3.47 per cent and 0.10 per cent per annum respectively during the study period. It means that if we eliminated the errors in aggregation of labour services then the role of total factor productivity will be insignificant.

Concluding Remarks

Thus after the removal of aggregation and measurement errors, Jorgenson-Griliches found that 96.7 per cent per annum rate of growth of the United States private sector economy output over the study period is explained by the growth in input, leaving 3.3 per cent due to change in total factor productivity or residual. The latter is in marked contrast to 47.6 per cent before correction of data.

Criticisms of Jorgenson-Griliches Approach

- As comparison of Denison, Jorgenson-Griliches present more realistic estimates of the sources of growth of the United States. They have corrected all sources of errors while Denison corrects only for errors in the measurement of labour services. Jorgenson-Griliches have shown that the residual or change in total factor productivity is very small as comparison to Denison due to advance in knowledge.

- However, some economists do not accept the Jorgenson-Griliches hypothesis, when the latter attribute virtually the whole of measured growth to increases in factor of production i.e., inputs.
- Denison point out that their extremely low estimate of change in total factor productivity is almost entirely due to the wholly unwarranted adjustment to the capital utilization series
- Further, Denison claims that there are very little difference between the results of Jorgenson-Griliches and traditional estimates of the total factor productivity growth, which is accounted by the removal of errors in the output series as claimed by Jorgenson-Griliches.
- Jorgenson-Griliches themselves indicate that the most serious weakness of their study is relative utilization of capital and labour to adjust capital and labour input to year-to-year variation as a result of discrepancies between them.

8. Summary

❖ The standard growth accounting exercises generate a Solow residual, which is typically viewed as a measure of technological progress.

❖ Recent theories of endogenous growth allow for a sharper perspective on this residual. Specially, the residual can be clearly interpreted within settings that allow for increasing returns and spillovers or in models in which technological progress is generated by purposeful research. These interpretations provide guidance for explaining the residual in terms of R&D outlays, public policies, and other factors.

❖ The standard growth-accounting exercises provide useful information within the context of modern theories of endogenous growth and that the recent theories can be used to extend the usefulness of traditional growth accounting. Hence, the older and newer approaches to economic growth are complementary.

❖ Several economists such as Denison , Kendrick, Jorgenson and Griliches and others have tried to quantify and break down the residual in to further several components. They contend that the residual is not a catch-all and that changes in output are due to changes of quantities and qualities of inputs, in economies of scale and advances in knowledge rather than the results of technical change, assuming a stable production function.