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Economics of Innovation: A Review in Theory and Models

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Abstract:
Innovation activities contribute essentially to the regional dimension and growth. The technological infrastructure and innovation capabilities affect not only the regional growth, but also the whole periphery and economy as well. There are a lot of problems and questions regarding the measurement of innovation activities at a regional level. This paper attempts to analyze the whole framework of innovation statistics and in particular to examine the measurement and also the statistical estimation of innovation activities. On this context, it's also aiming to emphasize and to review the appropriate techniques, the most common methods and the particular problems.

Keywords: *Innovation activities, Statistical measures techniques and methods, research and development.*

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1. Introduction: Looking for the Leading Indicators

The main expenditure aggregate used for international comparison is gross domestic expenditure on R&D (GERD), which covers all expenditures for R&D performed on national territory in a given year. It thus includes domestically performed R&D which is financed from abroad but excludes R&D funds paid abroad, notably to international agencies. The corresponding personnel measure does not have a special name. It covers total personnel working on R&D (in FTE) on national territory during a given year. International comparisons are sometimes restricted to researchers (or university graduates) because it is considered that they are the true core of the R&D system.

The use of research and technological data implied a lot of problems with the collection and measurement. The problems of data quality and comparability are characteristic for the whole range of data on dynamic socio-economic activities. However, most of the research and technological indicators capture technological investment in small industries and in small firms only imperfectly. Usually only, the manufacturing firms with more than 10,000 employees have established some research and technological laboratories, while industrial units with less than 1,000 employees usually do not have any particular research activities. Finally, the research and technological statistics concentrate mostly on the manufacturing sectors, while usually neglecting some service activities.

The collection of R&D data of regional statistics implied a lot of problems in comparison to data of national statistics. For the collection of regional statistics, we should take into the local differences and the difficulties. R&D units can operate in more than one region and we should allocate these activities between regions. Usually, regional statistics focused on the three first levels of NUTS (Nomenclature of Territorial Units for Statistics). Innovation indicators measure aspects of the industrial innovation process and the resources devoted to innovation activities. They also provide qualitative and quantitative information on the factors that enhance or hinder innovation, on the impact of innovation, on the performance of the enterprise and on the diffusion of innovation.

The variables common used variables for S-R&T activities are:

- R&D expenditures
- R&D personnel
- Patents of New Technologies.

Tables 1 and 2 illustrate some of the main type of variables in relation to the measurement of scientific and technological activities and also the main titles and Sources from which they derived. However, R&D statistics are not enough. In the context of the knowledge-based economy, it has become increasingly clear that such data need to be examined within a conceptual framework that relates them both to other types of resources and to the desired outcomes of given R&D activities. Similarly, R&D personnel data need to be viewed as part of a model for the training and use of scientific and technical personnel.

The term R&D covers three activities: basic research, applied research and experimental development. *Basic research* is “experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view". *Applied research* is also "original investigation undertaken in order to acquire new knowledge". However, it is directed primarily towards a specific practical aim or objective. *Experimental development* is "systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed". R&D covers both formal R&D in R&D units and informal or occasional R&D in other units.

Table 1: Innovation and Not Innovation Activities

			Innovation		**Not Innovation**
			New to the World	New to the Firm	Already in the Firm
Innovation	Technologically New	Product			
		Production Process			
		Delivery Process			
	Significantly Technologically Improved	Product			
		Production Process			
		Delivery Process			
		Organisation			
Not Innovation	No Significant Change. Change without novelty or other creative improvements	Product			
		Production Process			
		Delivery Process			
		Organisation			

Source: OECD (1981).

Table 2: Type of Variables, Titles and Sources for the Measurement of Scientific and Technological Activities

Type of Main Variables	***Titles and Sources***
Research and Development (R&D)	**Frascati Manual**: “Standard Practice of Research and Experimental Development” and also **Frascati Manual Supplement**: “Research and Development Statistics and Output Measurement in the Higher Education Sector”.
Technology Balance of Payments	**OECD:** “Manual for the Measurement and Interpretation of Technology Balance of Payments Data”
Innovation	**Oslo Manual:** OECD Proposed Guidelines for Collecting and Interpreting Technological Innovation Data
Patents	**OECD-Patent Manual:** “Using Patent Data as Science and Technology Indicators”
Scientific and Technical Personnel	**OECD-Canberrra Manual:** “The Measurement of Human Resources Devoted to Science and Technology”
High Technology	**OECD:** “Revision of High Technology Sector and Product Classification”
Bibliometrics	**OECD:** “Bibliometric Indicators and Analysis of Research Systems, Methods and Examples” (Working Paper – Yoshika Okibo).
Globalisation	**OECD:** “Manual of Economic Globalisation Indicators”
Education Statistics	**OECD:** “OECD Manual for Comparative Education Statistics”
Education Classification	**OECD:** “Classifying Educational Programmes: Manual for Implementation in OECD countries”
Training Statistics	**OECD:** “Manual for Better Training Statistics: Conceptual Measurement and Survey Issues”

Source: OECD/Eurostat (1997)

The reliability of R&D and innovation regional statistics is directly connected and depending on estimation-method and the application of statistical technique. Another important question on R&D and innovation regional statistics is the confidentiality and the collection-method of data-set that may be cover the whole or the majority of the local-units. For the statistical methods focused on a regional level, we can use either the ‘’local-units’’ (i.e. enterprises, office, manufacturing etc.) or the ‘’local-economic-units’’ (NACE codes, which is a division of national codes of European member states). Therefore, we can use the first method «top-to-the-bottom method» for the collection of aggregate R&D data (for the whole country) and after that on the distribution of these figures into a regional-level; the disadvantage of this method is that there is not a direct collection of data from the regions.

The second method «bottom-to-the-top method» for the collection of disaggregated R&D data (for the whole regions) based on the direct-collection at a regional-level and after that on the summation of these figures in order to obtain the aggregate-total R&D data (for the whole country); the advantage of this method is that there is a consistency in the summary of figures between regional and national level.

2. Theory and Models in Economics of Innovation

There is a huge literature suggesting and demonstrating that research and scientific indicators make an important contribution to the growth at the firm, industry and national levels. Most of these studies have investigated the relation between productivity, employment, growth and R&D.

2.1 The Input-Output framework

The structural decomposition analysis can be defined as a method of characterizing major shifts within an economy by means of comparative static changes. The basic methodology was introduced by Leontief (1953) for the structure of the US economy and has been extended in several ways. Carter (1960) has incorporated some dynamic elements with a formal consideration of the role of investment in embodied technical change. Chenery, Syrquin and others (1963) added elements of trade into this framework.

Growth decomposition analysis uses input-output techniques because they capture the flows of goods and services between different industries. Input-output methods exploit the inter-linkages effects and also search for the components of growth. In addition, input-output techniques allow us to calculate the contribution of *technical change* to output growth. The principal argument of the method of inter-industry analysis is to show explicitly the interdependence of growth rates in different sectors of the economy. Usually, two different compositional indicators are used to analyze the extent of structural change, the annual growth rate of real output in each industry and the share of national real output accounted for each industry.

Input-output tables are available both in current and constant prices. Following Kubo et al. (1986), we can consider the *basic material balance condition* for the gross output of a sector as given by:

$$X_i=W_i+F_i+E_i-M_i \qquad (\textit{material balance equation}), \qquad (1)$$

where:
X_i=the gross output,
W_i=the intermediate demand for the output of sector i by sector j,
F_i=the domestic final demand for the output of sector i,
E_i=the export demand, and
M_i=the total imports classified in sector i.

The gross output of sector i is the sum of output to intermediate demand plus the domestic final demand plus the exports less the imports. In the matrix notation the *material balance condition* becomes:

$$X=AX+F+E-M=(I-A)^{-1}(F+E-M), \quad (2)$$

where $(I-A)^{-1}$, the inverse of the coefficients matrix, captures the indirect as well as the direct flows of intermediate goods.

Holding one part of the material balance equation constant and varying the other components over time, the change in an industry's output can be decomposed into the following factors:

- technical change (corresponding to changes in the inverted I-A matrix);
- changes in final demand;
- changes in the structure of exports; and
- changes in the structure of imports.

This equation provides at an aggregate level a comprehensive picture of structural change for each country. It does not explain why the structure of an economy changed, but it describes how it came about and measure the relative importance each factor in each industry's growth.

Growth effects are analyzed in order to reveal how much output in each industry would have changed with the same growth rate for each element in the final demand category. When growth rates differ between the final demand categories, the resulting growth rates for the industrial output will also vary. The positive or negative effects of structural change affect the final demand categories.

2.2 Technological change in the Input-Output framework

Technological change plays an important role in the expansion and decline of sectors. Technology intensity and real growth rates of output can be used to classify individual industries into different performance groups. These groups can then be used to describe the patterns of structural change and to make comparisons among various countries.

The effects of technical change are analyzed in order to find out how much the use of primary inputs has changed, because of changes in the endogenous factors of the model. Furthermore, the effects of technical change on industrial output are analyzed, in order to reveal how much output in each industry has changed because input-output coefficients have altered.

A way of measuring changes in input-output coefficients is to compute the weighted average changes in the input-output coefficients of various sectors and to compare the matrices at two different points of time. For instance, we can use the following formula (3), in order to compute the weighted indices:

$$T_j = \frac{1}{\frac{1}{2}\Sigma(X_{ij}^2 + X_{ij}^1)} \Sigma\left[\frac{(A_{ij}^2 - A_{ij}^1)}{(A_{ij}^2 + A_{ij}^1)}(X_{ij}^2 + X_{ij}^1)\right] \quad (3)$$

where: A^2_{ij} is the elements of matrix of input-output coefficients for the second period,

A^1_{ij} is the elements of matrix of input-output coefficients for the first period,

X^2_{ij} is the matrix of inter-industry transactions for second period at constant 1975 prices,

X^1_{ij} is the matrix of inter-industry transactions for first period at constant 1975 prices.

This index measures the overall input changes in each of the n production sectors due to technological changes, changes in the prices, and product mix (the so called *Rasmussen index* of structural change).

The total change in sectoral output can be decomposed into sources by category of demand. The total change in output equals the sum of the changes in each sector and can also be decomposed either by sector or by category of demand.

The relations, (with the two intermediate terms combined), can be shown as following:

$$
\begin{array}{l}
DD_1 + EE_1 + IS_1 + IO_1 = \Delta X_1 \\
DD_2 + EE_2 + IS_2 + IO_2 = \Delta X_2 \\
\;.\qquad .\qquad .\qquad .\qquad . \\
\;.\qquad .\qquad .\qquad .\qquad . \\
DD_n + EE_n + IS_n + IO_n = \Delta X_n \\
\hline
\Sigma DD_i + \Sigma EE_i + \Sigma IS_i + \Sigma IO_i = \Sigma \Delta X_i = \Delta X
\end{array}
$$

where: DD_i=domestic demand expansion in sector i,
EE_i=export expansion in sector i,
IS_i=import substitution of final and intermediate goods in sector i,
IO_i=input-output coefficients in sector i,
ΔX_i=change in the output of sector i.

Reading down the columns gives the sectoral composition of each demand category, while reading across the rows gives the decomposition of changes in sectoral demand by different demand categories. When making comparisons across countries and time periods, it is convenient to divide the entire table by $\Sigma\Delta X_i$, so that all components across sectors and demand categories sum to 100. Alternatively, it is sometimes convenient to divide the rows by ΔX_i and then to look at the percentage contribution of each demand category to the change in sectoral output.

Table 3: Decomposition Formulas (*)

Sources of growth:	*Variable*	*being*	*decomposed*	
Domestic-final-demand expansion (FE)	Output ΔX	Val.Add. ΔV	Imports ΔM	**Empl. ΔL**
Export expansion(EE)	$B_0\hat{u}^f_0\Delta F$	$v_0B_0\hat{u}^f_0\Delta F$	$(m11f_0+m^w_0A_0B_0\hat{u}^f_0)\Delta F$	$\mathbf{l_0B_0\hat{u}^f_0\Delta F}$
Import-subst.of final goods (ISF)	$B_0\Delta E$	$v_0B_0\Delta E$	$m^w_0A_0B_0\Delta E$	$\mathbf{l_0B_0\Delta E}$
Import-subst.of interm. goods(ISW)	$B_0\Delta\hat{u}^fF_1$	$v_0B_0\Delta\hat{u}^fF_1$	$(I-m^w_0A_0B_0)\Delta m^wW_1$	$\mathbf{l_0B_0\Delta\hat{u}^fF_1}$

Technical change(IOA)	$B_0\Delta\hat{u}^w W_1$	$v_0B_0\Delta\hat{u}^w W_1$	$(I\text{-}m^w{}_0A_0B_0)\ \Delta m^w W_1$	$\mathbf{l_0B_0\Delta\hat{u}^wW_1}$
Change in value-added-ratio (IOV)	$B_0\hat{u}^w{}_0\Delta AX_1$	$v_0B_0\hat{u}^w{}_0\Delta AX_1$	$(m^w{}_0+m^w{}_0A_0B_0\hat{u}^w{}_0)\ \Delta AX_1$	$\mathbf{l_0B_0\hat{u}^w{}_0\Delta AX_1}$
Labour-productivity-growth (IOL)	-----	ΔvX_1	-----	-----
Labour-productivity-growth (IOL)	-----	-----	-----	$\mathbf{\Delta lX_1}$

Source: *OECD Document: Structural change and Industrial performance, 1992.*
Note:(*)the previous analysis can be extended to value added, employment, & imports.

At this stage, we can give an *alternative model*, which is known as the *deviation model* and measures changes in the relative shares of output. The deviation model starts from balanced growth, where it is assumed that all sectors grow at the same rate equal to the growth rate of total output. The comparison of changes in output shares and differences in growth rates reveals the direction and the pace of structural change. Japan represents the clearest example of structural change. The high technology sectors increased rapidly and contributed significantly to manufacturing's share of total output. In Japan the low technology sector showed the second largest loss of output share of all countries examined.

2.3 Catching Up and the Production Models

Higher levels of innovation activities tend to have a higher level of value added per worker (or a higher GDP per head) and a higher level of innovation activities than others. Following the technological-gap arguments, it would be expected that the more technologically advanced countries would be the most economically advanced (in terms of a high level of innovation activities and in terms of GDP per capita). The level of technology in a country cannot be measured directly. A proxy measure can be used to give an overall picture of the set of techniques invented or diffused by the country of the international economic environment. For the productivity measure, we can use the real GDP per capita as an approximate measure. The most representative measures for *technological inputs and outputs* are the indicators of patent activities and the research expenditures.

For the level of productivity, we can use as a proxy real GDP per capita (GDPCP). For the measurement of *national technological level*, we can also use some approximate measures; for instance, we can again use the traditional variables of *technological input* and *technological output* measures, (GERD and EXPA). The majority of empirical studies in the estimations between productivity growth and R&D follow a standard linear model; on this context we use a similar approach. The reason is that even though a more dynamic relationship exists, the data limitations (lackness of time series annual data on R&D activities for most countries) prevent the application of some complex models.

We can test the basic technological gap model (with and without these variables) reflecting the structural change, in order to decide to what degree these variables add something to the other explanatory variable of the model. We will use the external patent applications (EXPA) and gross expenditures on research and development (GERD) as proxies for the growth of the national technological activities, GDP per capita (GDPCP) (in absolute values at constant prices) as a proxy for the total level of knowledge appropriated in the country (or *productivity*). Investment share (INV) has been chosen as an indicator of growth in the capacity for economic exploitation of innovation and diffusion; the share of investment may also be seen as the outcome of a process in which institutional factors take part (since differences in the size of investment share may reflect differences in institutional system as well). For the structural change we used as an approximation changes in the shares of exports and agriculture in GDP.

We have tested the following version of the models:

GDP (or PROD) = f [GDPCP, EXPA (or GERD), INV], (basic model), (4)

GDP (or PROD) = f [GDPCP, EXPA (or GERD), INV, EXP], (5)

GDP= f [GDPCP, EXPA (or GERD), INV, TRD], (6)

The first model may be regarded as a pure *supply model*, where economic growth is supposed to be a function of the level of economic development GDPCP (GDP per capita with a negative expected sign), the growth of patenting activity (EXPA with a positive sign) and the investment share (INV with a positive sign). However, it can be argued that this model overlooks differences in overall growth rates between periods due to other factors and especially differences in economic policies.

The correlation between productivity and patenting is much closer than between productivity and research expenditure. When conducting an econometric analysis of the technological gap models, it is important to include the most relevant variables. For the level of productivity, as a proxy we can use real GDP per capita (GDPPC). For the national technological level we can use some approximate measures, for instance we can again use the traditional variables of technological input and technological output (GERD and EXPA). Following the model of Fagerberg (1987, 1988, and 1994) we can test the basic technological gap model (with and without these variables), reflecting structural change, in order to determine the degree to which these variables have added something to the other explanatory variable of the model. We can use external patent applications (EXPA) and gross expenditure on research and development (GERD) as proxies for the growth of national technological activities, and GDP per capita (GDPPC) (in absolute values at constant prices) as a proxy for the total level of knowledge appropriated in the country (or productivity).

Investment share (INV) has been chosen as an indicator of an improvement in the capacity for economic exploitation of innovation and diffusion; the share of investment may also be seen as the outcome of a process in which institutional factors take part (since differences in the size of investment share may reflect differences in the institutional system). The export variable also has the expected sign and the results support the hypothesis of structural change as a source of economic growth. The second model takes account of structural changes using as a proxy the share of exports in GDP. The third model uses an additional variable that reflects changes in the macroeconomic conditions and suggests that growth rates are seriously affected by changes in the terms of trade. The models are tested for EU member states.

` The basic model is tested for the variables of GDP, GDP per capita, external patent applications and investment as a share of GDP. The explanatory power (or the overall goodness of fit of the estimated regression models) is not very high, but this is not surprising for cross-sectional data. However there is a problem with interdependence between the variables. For this reason we shall focus on the relationship between productivity and innovation. Most of the variables have the expected signs.

Furthermore, a production function is by definition a relationship between output and inputs. For a single country, say ith, the production function may be written as:

$$y_{it}=F_i(X_{i1t},X_{i2t},.......,X_{imt},t), \qquad (7)$$

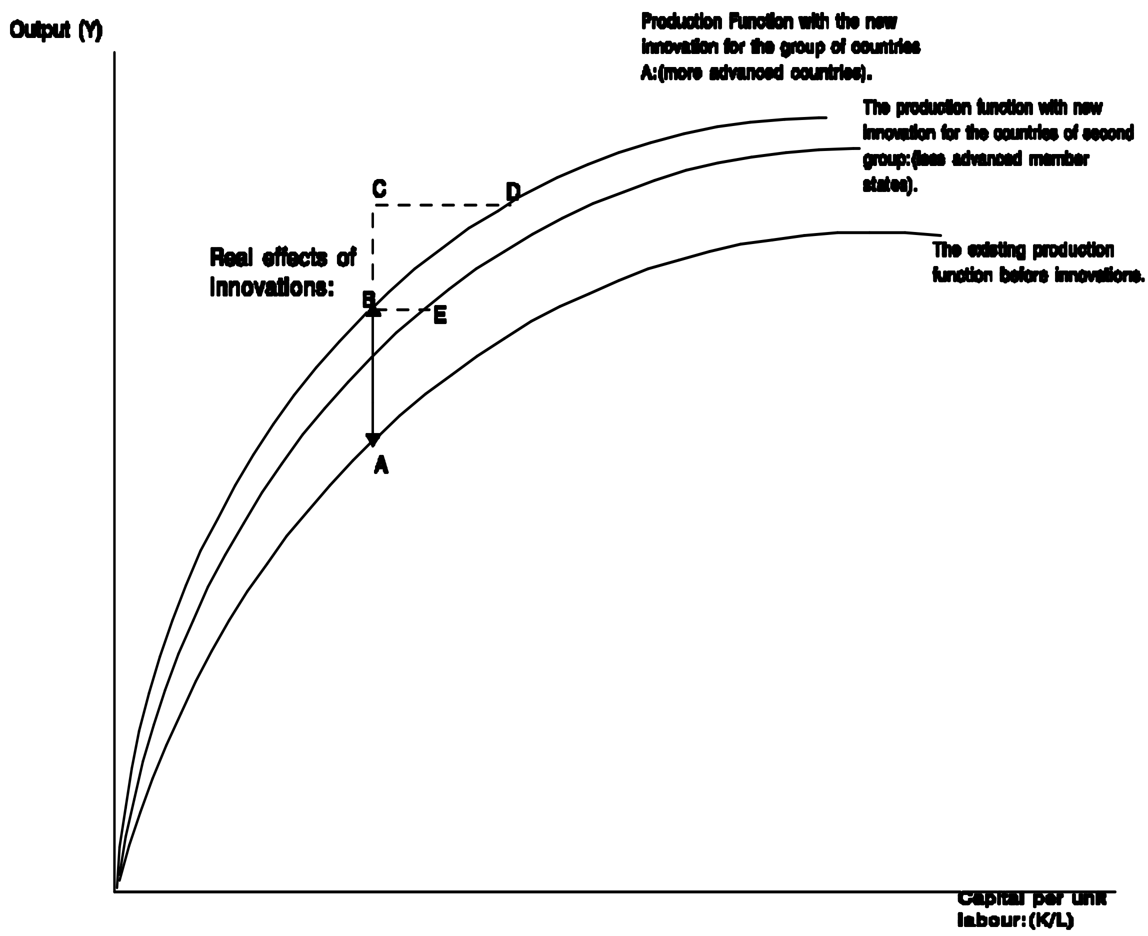
where: y_{it} is the quantity of output produced per producer unit and X_{ijt} is the quantity of the jth input employed per producer unit (j=1,2,....m) in the ith country for the period.

In a cross section study, technology can be regarded as given in each country, but this is clearly not in the case when we consider a single country over a period of time. The country's production function will shift as new and more efficient techniques are adopted. A major problem with time series data is to distinguish between increases in output resulting from movements along the production function (for instance, from increased inputs) and increases in output which occur because of shifts in the production function resulting from the technical progress. The problem of simultaneous equation bias is present with time-series data as with cross sectional data. However, there is a more serious problem with time series data that of the technical progress or innovation over time.

The concept of a production function plays an important role in both micro and macroeconomics. At the macro level it has been combined with the marginal productivity theory to explain the prices of the various factors of production and the extent to which these factors are utilised. The production function has been used as a tool for assessing what proportion of any increase in the output over time can be attributed first to increase in the inputs of factors in the production, second to the increasing returns to scale and third to *technical progress*.

Most studies of the production function (Solow 1957, Griliches 1967) have been handled under one or more traditionally maintained hypothesis of *constant returns of scale*, *neutrality of technical progress* and *profit maximization* with competitive output and input markets. Therefore, the validity or otherwise of each of these hypotheses affects the measurement of technical progress and the decomposition of economic growth into its sources.

Figure 1: Production Function and Technical Change



We can also assume that there is a production function that relates output to capital per unit of labour and also we also assume first that the economy is at the point A (where labour force growth is static and investment is at an average level). When a new technology is introduced there is an upward shift of the production function. Of course, the shift of the production function will be different across different countries. This shift of the production function implies additional output per person and probably this can lead to extra savings and consequently to more capital per worker, which means that the economy will moves along the production function. Figure 1, shows that the economy reaches the point E for less advanced countries and point D for more advanced countries. The real effects of innovation can now be measured by the distances AE and AD respectively.

The aggregate cost (or production) function is based on a cost function (or a production function), which is characterised by constant returns to scale:

$$C=F(P_K, P_L, Y, T) \qquad (8)$$

where: P_K, P_L, Y, T indicate the price of capital input, labour input, the value added and time.

3. Conclusions

This article attempts to identify the R&D activities and also to investigate the estimation-methods, the techniques of scientific and technological activities and the measurement problems. Series of R&D statistics are only a summary of quantitative reflection of very complex patterns of activities and institutions. In the case of international comparisons, the size aspirations and institutional arrangements of the countries concerned should be taken into consideration. One way of constructing reliable indicators for international comparisons is to compare R&D inputs with a corresponding economic series, for example, by taking GERD as a percentage of the Gross Domestic Product. However, its quite difficult to make detailed comparisons between R&D data and those of non-R&D series both because of the residual differences in methodology and because of defects in the non-R&D data.

The collection of R&D data of regional statistics implied a lot of problems in comparison to data of national statistics. For the collection of regional statistics, we should take into the local differences and the difficulties. In addition, we can use either the ''local-units'' or the ''local-economic-units''. The first method «top-to-the-bottom method» focused on the collection of aggregate R&D data (for the whole country) and after that on the distribution of these figures into a regional-level; the disadvantage of this method is that there is not a direct collection of data from the regions or the second method «bottom-to-the-top method» for the collection disaggregated R&D data (for the whole regions) based on the direct-collection at a regional-level and after that on the summation of these figures in order to obtain the aggregate-total R&D data (for the whole country).

Technological progress has become virtually synonymous with long run economic growth. It raises a basic question about the capacity of both industrial and newly industrialized countries to translate their seemingly greater technological capacity into productivity and economic growth. Usually, there are difficulties in the estimation the relation between technical change and productivity. Technological change may have accelerated, but in some cases there is a failure to capture the effects of recent technological advances in productivity growth or a failure to account for the quality changes of previously introduced technologies.

In the literature there are various explanations for the slow-down in productivity growth for OECD countries. One source of the slow-down may be substantial changes in the industrial composition of output, employment, capital accumulation and resource utilization. The second source of the slow down in productivity growth may be that technological opportunities have declined; otherwise, new technologies have been developed but the application of new technologies to production has been less successful. Technological factors act in a long run way and should not be expected to explain medium run variations in the growth of GDP and productivity.

Technological gap models represent two conflicting forces; innovation which tends to increase the productivity differences between countries and diffusion which tends to reduce them. In the Schumpeterian theory, growth differences are seen as the combined results of these forces. Research on *why growth rates differ* has a long history which goes well beyond growth accounting exercises.

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