2. TECHNICAL CHANGE AS EXOGENOUS OR ENDOGENOUS FACTOR IN THE PRODUCTION FUNCTION MODELS. EMPIRICAL EVIDENCE FROM ROMANIA

Gheorghe ZAMAN*
Zizi GOSCHIN**

Abstract

As technical change is nowadays largely accepted to be an engine of economic growth, researchers have tried to include it explicitly in the economic growth models, either as an exogenous or endogenous factor of influence. Using the framework of the aggregate Cobb-Douglas production function in its classical form, as well as in several refined variants, we estimated the elasticities of production factors for Romania over the 1990-2007 period, finding that technical progress has had a small contribution to the economic growth.

Keywords: technical change, R&D, exogenous and endogenous factors, growth models, Cobb-Douglas production function

JEL Classification: O47, O30

Introduction

In the 20th century, technological change became largely recognized as the key factor of economic growth, but the economic theory firstly treated it as a mere 'residual', the unexplained part remaining after the contributions of an increased quantity and quality of capital, labor and natural resources in output growth have been accounted for. Technological change, in this sense, represents the impact of ***exogenous*** forces, whereas some researchers simply consider this residual of the growth models to be a measure of our economic ignorance.

* *Gheorghe Zaman, Corresponding Member of the Romanian Academy, Director of the Institute of National Economy, e-mail: gheorghezaman@ien.ro*
** *Zizi Goschin, Institute of National Economy, e-mail: zizgoschin@yahoo.com*

The theory of economic growth reconsidered recently the nature of technological change and the concept of knowledge. Since technical progress is closely associated with the knowledge emerging from research and development activities, ***endogenous*** technical change is considered to be generated by formal R&D activities. Therefore, the new growth economic theory included R&D as a factor of influence in the macroeconomic models.

The endogenous or exogenous nature of the technological change refers to its source: endogenous change is internal to the national economy, being created by domestic private or public enterprise, while exogenous change is external, originating from foreign sources.

Starting from these overall considerations, we attempted to model the economic growth in Romania in the last two decades by explicitly taking into account the technical change in its exogenous and endogenous form. The present paper extends our previous studies on aggregate production functions for Romania (Zaman and Goschin, 2007a, 2007b), including the variables R&D expenditures, R&D investments and R&D workforce as new factors in the production function model.

The paper is structured as follows. In the next section, we give a short overview of the relevant literature, discussing the role of technological change as an exogenous or endogenous factor in the economic growth models. Section 3 provides some explanation on the data used and the results of the model estimations for different variants of the classical and R&D based Cobb-Douglas production functions. Section 4 provides concluding comments and directions for future research.

Technical progress in the models of economic growth

Although technological progress, managerial improvements, and innovation in general are nowadays largely regarded as key contributors to economic growth, such concepts entered relatively late the history of economic thought. The present approach to the topic of technological change in the mainstream economic literature is largely based on Schumpeter's writings in the early 1900s. Schumpeter (1939) defined technical progress in terms of production function, which describes the way the production output varies according to the quantity and quality of the input factors. The technological change represents the factor that shifts the production function.

The production functions originated from the works of Cobb and Douglas (1928), as tools for testing macroeconomic hypotheses related to marginal productivity and competitiveness. The increasing interest in growth and technological change produced an expansion of the production functions in the neoclassical models of economic growth. New technical progress-related elements were added to the analysis, such as total factors productivity and efficiency (Tinbergen, 1942; Stigler, 1947; Fabricant, 1954), capital efficiency as measured by embodied technical progress (Mairesse, 1978), differences in public and private investments in research and development (Griliches, 1980; Griliches and Mairesse, 1984), the presence of economies of scale in production (Griliches and Ringstad, 1971; Mairesse, 1975), the diffusion of information technology (Brynjolfsson and Hitt, 1995; Lichtenberg, 1995).

The early production function empirical studies focused on technological change were summarized by Solow (1957), who concluded that technical progress is the source of the largest part (87.5%) of the entire economic growth. Starting from the standard neoclassical approach in a Cobb-Douglas model with two production factors (capital and labor), Solow advanced the concept of an aggregate production function such as:

$$Y = f(K,L;t), \tag{1}$$

where: Y is the output and K and L represent capital and labor inputs, and the variable t (time) is expressing in the production function the ***exogenous technical progress***. Solow explicitly called technical progress any shift of the production function, including the improvement of labor force training. When technical progress is neutral, the equation (1) may be reformulated as:

$$Y = A_t\, f(K, L). \tag{2}$$

where: A_t is a function of time which allows for neutral technical progress.

Differentiating this equation with respect to time and dividing the result by Y it results:

$$\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + \alpha\frac{\dot{K}}{K} + \beta\frac{\dot{L}}{L} \tag{3}$$

where: á and â represent the share of capital and labor in the output and $\frac{\dot{A}}{A}$ is the technical progress determined as a residual based on the output change which cannot be explained by increasing capital and labor.

Under the assumption of constant returns to scale (á= 1-â), equation (3) becomes:

$$\frac{\dot{y}}{y} = \frac{\dot{A}}{A} + \beta\frac{\dot{k}}{k}, \tag{4}$$

where: $Y/L=y$ (output per man hour) and $K/L=k$ (capital per man hour).

Based on relation (4), the technical index can be computed by using series of labor productivity, capital per man-hour and the share of capital.

Solow's model dominated empirical studies up to the early seventies, although it does not allow for a more in-depth analysis of the determinant factors of technical progress and the measurement of their contribution to economic growth. Other researchers have attempted to decompose growth into contributing factors using refined models that allowed for such factors as human capital, technological improvements embodied in capital, multiple sectors and so on. As the statistical methodology and the national accounts improved, the initial conclusion of Solow, which attributed to technical progress almost the entire economic growth, began to fade. Nevertheless, there are relatively more recent studies (Jorgenson 1990, Denison 1985, Matthews *et al*., 1982) which suggest that an important part of economic growth (about one-third) is "residual growth".

In the growth theory, technological change is considered to express the impact of new knowledge on the production function of the firm or nation. This new knowledge may be exogenous if generated outside the economic process or endogenous if it emerges from within the economic process. The hypothesis of the exogenous character of the technical progress in the neoclassical models of economic growth was challenged earlier by new theoretical and empirical developments. Researchers have attempted to demonstrate the ***endogenous character of the technical change*** (the term was first introduced by Lucas in 1966) both from a theoretical perspective (Arrow, 1962; Kaldor and Mirrlees, 1962) and from an empirical one (Aghion and Howitt, 1992, 1998; Romer, 1990).

The endogeneity or exogeneity of technological change refers to its source. The exogenous technological change is generated outside the economic process, *falling like manna from heaven* (Scherer 1971, p. 347), while the source of endogenous technological change is the economic process itself, in response to profit and loss.

Investing resources in R&D and others types of knowledge, such as human capital, generates innovative opportunities that explain endogenous technological change. Griliches (1979) was the first to introduce in the production function the R&D stock, computed as accumulated value of R&D expenditure after depreciation, to be one of the variables in his so-called knowledge-capital model. Many empirical studies that followed estimated production functions of the Cobb-Douglas type including various input indicators, and, as a rule, the expenditures for research-development, either aggregated or decomposed into components such as fundamental and applicative research, or private or governmental research (Griliches, 1980; Mansfield, 1980; Nadiri, 1980; Scherer, 1982; Terleckyj, 1974; Griliches and Lichtenberg, 1984).

The standard knowledge production function model includes the stock of knowledge as a separate production factor in the standard Cobb-Douglas function:

$$Y_t = A \cdot D_t^{\beta} \cdot K^{\alpha 1} \cdot L^{\alpha 2} \cdot e^{\mu t} \tag{5}$$

where: Y_t is output, D_t is the stock of knowledge, L_t is the labour input, K_t is capital input, A is a constant and μ is a trend variable which catches other influences.

This is the typical evaluation model of total productivity of R&D and efficiency factors. From (5), the total factor productivity (TFP) is measured as:

$$TFP_t = Y_t / (K,L) \tag{6}$$

Estimates of the effect of innovation on total productivity of factors can be obtained (Griliches and Lichtenberg, 1984) either by using a measurement of the R&D stock of capital, as in the relation:

$$\log TFP_t = \log A + \beta \log D_t + \mu t \tag{7}$$

or by using a measurement of the R&D intensity (depending on output) in a regression relationship of the change of the total productivity of factors:

$$d \log TFP_t = \rho \frac{R_t}{Y_t} + \mu \tag{8}$$

where: R_t is the R&D flow, in contrast to D_t, which represents the accumulated capital of R&D.

Equation (7) offers a measurement tool of output elasticity depending on scientific knowledge (parameter β), while the equation (8) represents a measurement tool of the social efficiency (profitability) of scientific knowledge (parameter ρ), R and Y being measured by the same unit. The quality of statistical data and the area of interest determine the selection of the method of measurement.

From the theoretical viewpoint, applying these two methods faces the difficulty of separating knowledge from the other factors of the production function. The total factor productivity is usually estimated by subtracting from output the capital and labor factors, weighted by their specific shares. Under perfect competition, the price of the production factors is equal to their marginal productivity; hence, their shares in output are equal to their exponents from the production function, but under imperfect competition, measuring the total productivity of the factor would cause errors (Hall, 1990).

From the empirical point of view, there are difficulties of measurement, especially in the case of value added and research-development variables. Value added can be affected by several errors, the most severe being generated by the use of gross product deflator for building the real value series (Stoneman and Francis, 1994). R&D data cause even more problems due to the difficulties in defining the variable, choosing the lag, and adjusting for depreciation and inflation (Griliches, 1988). A major difficulty relates to measuring innovative outputs. From all available data on R&D inputs and outputs, R&D expenditures are most frequently used, along with the number of patents, the technological balance of payments, machinery and tool import, and dissemination. This choice of R&D expenditures as the main measure of input in innovation is heavily based on reasons of availability and correctness of data. Another major issue concerns the cyclical nature of the total factor productivity data (Cameron and Muellbauer, 1996).

The new theory of economic growth represented the starting point for a series of models where growth was driven by the technical progress endogenously resulting from the research-development efforts of the economic agents pursuing maximization of profit. This hypothesis implies the fact that the funds allotted to the R&D sector and probably other governmental policies may influence the long-term economic growth rate.

All modern developments of Cobb-Douglas functions are included under the cover of the ***New Growth Theory***, the most important contributions to it being the ones of Romer (1990), Aghion and Howitt (1992), Grossman and Helpman (1991). In contrast to the Solow model, in the works of these researchers, growth is endogenously generated by the R&D activity, any increase in level of resources allotted to the R&D sector triggering an increase in the economic growth rate.

The New Growth Theory views technological progress as a result of economic processes. Unlike previous theories which treated technology as a product of non-market forces, as exogenously given, the New Growth Theory has internalized technology in a type of model showing how markets are functioning and how knowledge and technology, unlike physical objects, are producing increasing returns as a driving force of economic growth.

The exponents of the new growth theory explicitly modeled knowledge as an output quality of the research-development sector and proved that, contrary to the neoclassical conclusions of the diminishing-returns technology, the introduction of the human capital changed the production function into one with increasing returns.

The aggregate production function in the new growth theory differs from the neoclassical one by entering the human capital H as a new factor of production (***the***

augmented Solow model), apart from the physical capital K and labor L: *Y= F(K, L, H, A).* Moreover A is no longer a constant, but a function of the stock of knowledge from the R&D, which is offsetting the diminishing returns of the other inputs by increasing marginal productivity (Romer, 1986).

Lucas (1988) reached similar conclusions. He showed that the human capital in the economy had a positive externality effect, since it affected the productivity of individual firms even though it was not involved in individual profit-maximizing decisions, and this explained its potential for increasing returns to all factors of production.

According to Romer, knowledge is an uncompetitive (non-rivalry) good and at the same time a good exclusively based on patents and copyright, which motivates companies to develop R&D activities in order to obtain the corresponding monopoly profit (Romer, 1990).

The approach of Aghion and Howitt is based on Schumpeter's idea of "creative destruction", a competitive process by which new innovations diminish or eliminate the value of older ones, which they replace (Aghion, Howitt, 1992).

Several models from this category are either "horizontal differentiations" models where growth is generated by the development of new products or "vertical differentiations" – models of quality improvement, where quality (and implicitly productivity) of some intermediary goods constantly increases therefore supporting long-term growth.

The fundamentally different nature of investments in knowledge has a central place in ***the endogenous economic growth model of Romer*** (1990). He introduced a new modeling strategy focusing on the determinants of technology itself. The model has four factors: capital, labor, human capital and technology. Capital K is represented by goods of long use for manufacturing final goods with a variety degree depending on the technological level of production. The labor factor L refers to unskilled labor. Knowledge is separated by the rival (competitive) component embedded in individuals – human capital H represented by education and on-the-job training – and an endogenous non-rival technological component, A, which is independent from individuals and which can be accumulated without limits. Technology is represented by a stock of manufacturing industrial models (designs) of goods, which are accumulated in time, as a result of research efforts. Fabrication models are excludable from the viewpoint of their direct use in production, meaning that only the owner of the patents may use them. Still, increasing the general stock of knowledge and generating new technological models, each new product that emerges contributes indirectly and non-exclusively to increasing production. In conclusion, technology is only partially excludable.

The New Growth Theory is helping to understand the ongoing change from resource-based economy to a knowledge-based economy. According to Romer (Romer, 1993, p.345):"*No amount of saving and investment, no policy of macroeconomic fine-tuning, no set of tax and spending incentives can generate sustainable economic growth unless it is accompanied by the countless large and small discoveries that are required to create more value from a fixed set of natural resources*".

Increasing returns as a pillar of the New Growth Theory, associated with the non-rivalry aspects of knowledge, have a series of implications for economic theory and practice such as: almost limitless opportunities for growth; market tendencies to under-invest knowledge; knowledge-based economy tends towards monopolistic competition; possibility of multiple equilibrium.

Based on these overall considerations, in the next section we have used the Cobb-Douglas production function framework in order to carry out the analysis of technical progress from both exogenous and endogenous perspective, emphasizing its influence on Romanian economic growth.

Classical Cobb-Douglas and R&D based production functions estimated for Romania over 1990-2007 period

This section aims to analyze, by means of the Cobb-Douglas production function methodology, the driving forces of Romanian economic growth in 1990-2007, focusing on the role of technical progress captured in its exogenous and endogenous forms.

The Cobb-Douglas model is a common choice in empirical studies on the factors of economic growth because it has some attractive features. Besides being easy to estimate, its parameters represent the elasticities of the increment of economic output with respect to changes in the variables, and these elasticities are constant, thus indicating the shares of the production factors in the total output. Although this model implies some limitations due to the simplifications on which this view is based we believe this approach to be useful for our research purpose.

The model of the Cobb-Douglas type aggregated production function was estimated envisaging both the classical approach of technical change as a residual factor and the new growth theory approach of technical progress endogenously generated by research and development activities. Considering the large role played by R&D activities and related investments in creating technological progress, different variables related to research and development activities in Romania were included in the Cobb-Douglas production function model. The analysis was undertaken at both national and regional scale, using time series and cross-sectional data, respectively. Time series datasets were built for GDP, gross fixed capital formation, employed population, total research-development expenditures, private R&D expenditures, public R&D expenditures, R&D employees in the public and in the private sector, for the period 1990-2007. The annual values were transformed into constant 1990 prices, using the GDP deflator. The time span envisaged by our analysis was limited by the available comparable data issued by the Romanian official statistics.

The successive changes in statistical methodologies for measuring the research-development activities are a serious obstacle to building long series of comparable statistical data and we had to use different estimation methods in order to construct our datasets. For instance, until 2000 R&D employees and R&D investments were broken down by type of ownership into public, mixed and private sectors, but only majority state and majority private sectors were used afterwards. In order to ensure comparability for a longer time series, we had to split the mixed sector into majority-state-owned and majority-private by using as a distribution key the average shares of the public and private sectors in the previous years.

Gross fixed capital formation was used as a proxy for the production factor capital. Even if these data do not reflect entirely the production factor capital, they currently represent the best available information in the Romanian official statistics.

Total research-development expenditures are used in this model as a measure of total investments (material and intangible) in the R&D sector. The construction of the R&D data series is usually the key issue for this type of analysis. In many studies, the R&D stock is calculated as the accumulated value of R&D expenditure after depreciation, a procedure which implies the assumption that all of the R&D expenditure is accumulated with 100 percent certainty and that the R&D stock depreciates with a certain fixed rate. Since long time-series data on R&D are rarely available, other studies assume that the growth rate of R&D flow is equal to that of R&D stock, which implies that the ratio of R&D expenditure to R&D stock is stable. The estimation model in this paper uses only information on R&D expenditure, not R&D stock, which brings about the advantage that there is no need for strong assumptions with regard to the R&D activity, such as a fixed rate of depreciation and the linear and certain accumulation of knowledge.

The labor production factor was divided into two components: *total employed population outside the research-development sector* and *the number of employees in R&D*. The same type of division was applied to the capital production factor.

Several growth models were applied using the Cobb-Douglas production function framework in its classical form with exogenous technical change and also some refined variants that allow for including new variables that reflect the R&D activity as a proxy for endogenously generated technical change.

Model 1. The Cobb-Douglas production function with exogenous technical change

Starting from the standard neoclassical model, we have used first a Cobb-Douglas production function with *Hicks-type neutral technological change* (Hicks, 1932), in the following form:

$$Y= A\, K^{\alpha}\, L^{\beta} e^{\lambda t}, \qquad (12)$$

where: $\alpha, \beta, \lambda > 0$, α and β are output elasticities with respect to capital and labor, respectively, the parameter λ is related to technological change, *t* represents time variation and A is a constant.

The component $e^{\lambda t}$ captures the Hicks neutral technological change that does not modify the elasticity of substitution between the factors of production.

We proceeded next to the estimation of the parameters of the aggregated production function for the 1990-2007 period using the Eviews software package and got the following results:

$$GDP = 0.021K^{0.3564}\, L^{0.7783}\, e^{0.0105t} \qquad (13)$$

Lagged models were further applied by using a one-year lag for K and L and different variants (1, 2 or 3 years) for the technological change captured by the residual component $e^{\lambda t}$. The results were similar, regardless of the amplitude of the lag:

$$GDP = K^{0.4098}\, L^{03377}\, e^{0.0105t} \qquad (14)$$

The lagged models should be preferred because the investments that we used as a proxy for the capital factor K become fully productive in time and the technological progress also needs time to reach its potential economic impact.

The usual statistical tests were performed in order to check the regression results from the previous models: the proportion of variance accounted for the model (R^2) is very high, the Durbin-Watson statistic is within the accepted statistical limits, showing no autocorrelation of errors, and the computed Fisher statistic exceeds by far its critical value. The estimates of the model parameters are highly significant as well.

Table 1

Exogenous versus endogenous contribution of technical change to GDP growth

Production factor	Factors' shares (%)			
	Model 1		Model 2	
	no lag	*lagged*	*no lag*	*3 year lag*
Capital K	31.12	54.82	54.16	69.18
Labor L	67.96	45.18	43.60	40.84
Exogenous technical change	0.92	1.40	-	-
Endogenous technical change*	-	-	-2.24	-10.02

**Based on R&D expenditures.*
Source: Authors' computations.

Of special interest is the analysis of the production function parameters and the economic policy conclusions that might be derived from it. Thus, the estimated parameters allow for measuring the contribution of the production factor capital K, labor L and residual $e^{\lambda t}$ (which stands for exogenous technical change) in obtaining the output Y as $\frac{\alpha}{\alpha+\beta+\lambda}$, $\frac{\beta}{\alpha+\beta+\lambda}$ and $\frac{\lambda}{\alpha+\beta+\lambda}$, respectively. The results of this computation are given in Table 1.

The outcomes of model 1 indicate that the exogenous technical change has an extremely small contribution from 0.92% to 1.40% in GDP growth, depending on the lag (Table 1). This should raise concern and alert the decision makers with regard to the mix of economic and social policies necessary for increasing the contribution of technological progress, especially if we take into consideration the international trend towards the knowledge-based society. Technological advancement, the primary factor of contemporary economic growth, as demonstrated by the experience of developed countries, seem to act with extremely modest effects in the Romanian economy.

Model 2. The Cobb-Douglas production function including R&D expenditures

A different perspective on the source of technological progress is obtained by introducing the R&D expenditures into the standard Cobb-Douglas model in order to capture the endogenous technological change, considering the no-lag variant:

$$GDP = K^{0.4259}\, L^{0.3428}\, R^{-0.0176} \tag{15}$$

and the lagged model (one-year lag for K and L and three-year time lag for R):

$$GDP = K^{0.5138} L^{0.3033} R^{-0.0744} \qquad (16)$$

where: R is the annual expenditure on R&D (in constant prices).

As previously stated, the lagged model is preferable, especially for R&D expenditures, which take time to reach their full growth potential. Alternative estimations with different values of the lag, for the purpose of discovering the sensitivity of R, showed that from a statistical perspective a three-year lagged model is best fitted. This result is in line with other empirical studies that indicate a lag time of 3 to 5 years of the returns on R&D investment.

The statistical tests performed for this model also gave good results; all the estimated coefficients are highly significant.

In this model the capital surpasses by far the labor share in GDP growth and the endogenous technical change has a negative contribution (Table 1), indicating the economic underperformance of the R&D sector. From a statistical perspective, the negative sign of the estimated coefficient of the variable R is explained by its divergent movement as compared to GDP: while GDP was in an upward trend for the largest part of the period under consideration, and its growth accelerated in the last years, R&D expenditures mostly declined or had very modest increases since 1990, still remaining under that level.

Model 3. The Cobb-Douglas production function including R&D investments and employees

In the standard Cobb-Douglas model, the two production factors, labor and capital, are both decomposed into components in order to account separately for the R&D capital and labor inputs. Using aggregated data for the period 1990-2007, and considering a three-year lag for the R&D variables and one-year time lag for the other variables we have obtained the following estimation of the production function:

$$GDP = K^{0.5374} K_R^{-0.0012} L^{0.3397} L_R^{-0.0764} \qquad (17)$$

where: K – gross fixed capital formation (excluding investment expenditure in R&D);

K_R – capital investments in research-development;

L – employed population outside the research-development sector;

L_R – number of employees in the research-development sector.

The usual statistical tests employed for this model produced good results on the whole, but high standard errors of the estimate of K_R and L_R make it difficult to come to definite conclusions. Based on the estimates of the production function parameters we have computed the contributions of the factors to GDP growth. The results indicate capital and labor shares similar to the previous model (67.22% for capital and 42.49% for labor) and negative influences of investments in R&D (-0.15%) and R&D employees (-9.55%). The R&D influence from the previous model is now split up into its capital and labor components.

Negative returns on R&D investments and employees indicate that these variables have moved against GDP on a consistent basis (Appendix 1). The negative impact of the labor force employed in R&D on GDP growth in Romania can be explained by the permanent drop in number of R&D employees after 1990, a development which goes against international trends. To this are also added other negative influences on the research-development personnel: emigration abroad of a significant part of the highly-skilled labor force (brain-drain), the relation brain-loss_brain-win being disadvantageous in the case of Romania; the ageing of the research labor force; migration of researchers to other better paid sectors; the diminished sizes of the staff with research tasks at company level; weak connections with the international scientific community, partially explicable by low international mobility of Romanian researchers, especially before 1990, etc.

Model 4. The Cobb-Douglas production function including R&D inputs in the public and in the private sector

Knowledge creation calls for high thresholds of R&D investments conducive to economic growth and development, and both the public and the private sector are contributing to it. In modern economies, fundamental research relies heavily on public funding, from the viewpoint of quality and scale, while knowledge-development within firms, as a major component of R&D, is mainly the result of private or private-public funding. Thus, a division of both labor and capital production factors for R&D into public and private sectors can be useful for explaining their separate contributions to economic growth.

The use of this public-private R&D division in the Cobb-Douglas production function brought about the following results:

$$GDP = K^{0.4562}\, K_{RS}^{-0.0549}\, K_{RP}^{0.0007} L^{0.3716}\, L_{RS}^{-0.1247}\, L_{RP}^{-0.0191} \qquad (18)$$

where: K_{RS} and K_{RP} – capital investments in R&D in public and private sector;

L_{RS} and L_{RP} – the number of employees in R&D in public and private sector.

As for the previous models, a three-year time lag was considered for all R&D variables and one-year lag for the other variables. The model passed all usual statistical tests, except for the significance test for the coefficient of $K_{RP,}$ due to its high standard errors. Therefore, this value should be used warily.

The results of model 4 are very challenging from the viewpoint of the complementarity (competition) between public and private R&D capital and labor force. Further analyses are needed to determine strong and weak points in both public and private R&D sectors.

As a preliminary conclusion of the model results, one may mention that in both private and public sectors the R&D efficiency of labor and capital is unsatisfactory, special policy instruments being necessary for a radical improvement in these sectors.

In this context, a special place has to be devoted to the relationship between national R&D sector and firms with foreign capital located in Romania, which are not very much interested in developing their own research activities. The parent companies are directly delivering to their subsidiaries in Romania the main R&D results obtained in their research centers and lab headquarter abroad.

Model 5. The Regional Cobb-Douglas production function including R&D expenditures

The statistical precision of the parameter estimates from any model heavily relies on the quantity and the quality of the available data. The quality of the estimates can be considerably improved by combining time series and cross-sectional (regional) data into a panel dataset. Thus, a sample of time series data ranging from 2000 to 2006 and one of regional data (the eight Romanian development regions) were pooled in order to provide a richer set of information (56 values/observations) for estimating the production function model. The variables of this R&D regional model of production function are:

- output: annual Gross Domestic Product by region;
- capital: gross fixed capital formation by region; in order to estimate it we had to split up the national gross fixed capital formation using regional gross investments (in industry, constructions, transport and services) as a distribution key;
- labor: annual employed population by region;
- R&D capital: annual R&D expenditures by region as a proxy for the investments in the research and development sector;
- R&D labor: annual R&D employees by region.

We obtained the following estimations:

$$GDP = 3.022\, K^{0.3002}\, K_R^{0.0494}\, L^{0.5369}\, L_R^{0.0973} \tag{19}$$

where: GDP – output: Gross Domestic Product;

K, K_R – capital, R&D capital;

L, L_R – labor, R&D labor.

The parameters of this model were estimated as usual with the Eviews software package and the model was validated by usual statistical tests.

Because of regional data availability, this model is envisaging a shorter time span (2000-2006) as compared to the previous models (1990-2007), thus providing the perspective of a period of sustained economic growth. The regression results changed accordingly, indicating a major shift in the factor contributions to the economic growth, especially for the R&D variables, all having positive coefficients.

Table 2

Factor shares in GDP growth based on regional panel data, 2000-2006

Production factors	Factors' shares in GDP (%)
Capital	30.51
R&D expenditures	5.02
Labor	54.58
R&D employees	9.89

Source: Authors' computations.

The main novelty is an increased contribution of the employed population to the economic growth, as the panel data estimates of the Cobb-Douglas production function clearly show that in the recent years the labor had a much higher share than the capital in the GDP growth (Table 2), mainly based on labor productivity improvements. This statement holds on for the entire economy and for the R&D sector as well. Both R&D expenditures and employees have had a significant positive impact on the Romanian economic growth during 2000-2006.

The analysis of the technological change contribution to economic growth undertaken for various models, datasets and time-horizons pursues to identify a balanced position between the dangers of over- or under-investment in certain activity sectors, aiming at achieving the optimum, which would be materialized in a superior dynamics of the efficiency in Romania comparatively to other countries, this being a fundamental condition of economic convergence.

Summary and final remarks

Scientific research broadens the knowledge horizon and improves opportunities for satisfying the needs of the human society as well. In the last decades, the rapid growth in research and development expenditures and their orientation towards practical, exacting purposes have determined an increased interest in learning about their efficiency by explicitly including R&D in the economic growth models.

The assumption that there is an exogenous character of technical progress adopted by the neoclassical theory of economic growth was early challenged by new theoretical and empirical developments. Under the theoretical aspect, researchers have attempted to prove the endogenous character of technical progress, while from the empirical viewpoint they have tried to model the technical change by including R&D data into the economic growth models. Many of these empirical studies use production function models that might be interpreted as pertaining to the category, which renders the effects of technological change endogenous. A new class of endogenous economic growth models (Romer (1990), Grossman and Helpman (1991a and 1991b), and Aghion and Howitt (1992) aimed to explain the role of technological progress as the primary determinant in the growth process and treated it as an endogenous variable based on a knowledge/technology production function that describes the evolution of knowledge creation.

This study aimed at estimating the contribution of the technological change to the Romanian economic growth in a Cobb-Douglas aggregate production function framework using both the neoclassical model of exogenous technological change and the knowledge production function that includes different R&D-related variables to account for endogenous technological progress. The estimations from various models all indicated an disappointingly low contribution of the technical progress in Romanian GDP growth.

The lack of “critical mass” of R&D funding and labor force is one of the main causes of the economic and social underperformance of the sector, associated with insufficient coherence of policy instruments and strategic approaches on medium and long terms. The negative impact of the labor force employed in the R&D sector on GDP in Romania is explained by the constant drop in number of employees after 1990, and also by means of other negative influences such as brain-drain, ageing of the labor force in the research sector, migration of researchers to other better paid activity sectors, the diminished size of the staff with research tasks at company level, and the weak connections to the international scientific community, etc.

The New Growth Theory suggests for central and local public authorities the following strategic rigors aiming at increasing the role of R&D in economic and social domains:

in economic growth, all kinds of knowledge and ideas, whether large or small, are playing a determinant role, including learning by doing; knowledge-based growth is stimulating the self-reinforcing cycle (virtual circle) in the sense that faster growth triggers new knowledge which in turn is the base of further growth; focusing on creating new knowledge both in universities and industrial sectors separately and/or in close and permanent cooperation; taking into consideration the positive feedback and quasi-chaotic development patterns of knowledge-based growth which implies new techniques of risk management; the risk in the R&D sector is greater on medium and long term, especially in relation to cutting R&D funds or eliminating them; the geographic pattern of economic growth could be started and shaped by the ability of institutions and decisions makers to boost knowledge creation and diffusion at both macro and micro levels where public-private partnership embrace specific schemes and ways of implementation.

The increased investments in research-development and innovation can be conceived but in a coherent, comprehensible framework, in which all production factors are involved in a convergent manner, in contrast to the current situation in Romania, marked by the lack of complementarity, of coordination in the capital-labor relation, which are shown sometimes under opposite forms: machinery and tools at high technical level which are not used at their full potential due to the insufficient training of the personnel, but also well-trained workers who can no longer put to good use their creativity in the absence of the corresponding material capital. Increasing the volume of public and private investments as well in R&D must be accompanied by their careful allocation by fields and sectors depending on the specialization capacity of Romania in this field in terms of efficiency and high economic, social, technological and environmental competitiveness.

This study can only be regarded as a first step in R&D-based models for explaining the determinants of endogenous economic growth in Romania. Since the period of time under consideration is relatively short and includes the complex and difficult years of transition to the market economy, further investigations using different production models for a longer time span must follow in order to provide better estimates of the nature and the impact of technological change in Romania. Important lessons could be learned from the impact of worldwide financial and economic crisis, the impact of which could radically change the relationships between the endogenous factors of technological progress.

References

Aghion, P. and P. Howitt (1992), “A Model of Growth through Creative Destruction”, *Econometrica*, pp. 323-351.

Aghion, P. and P. Howitt (1998), “*Endogenous Growth Theory* “, Cambridge: MIT Press.

Arrow, K. (1962), “The economic implications of learning by doing”, *Review of Economic Studies*, 29: 155-73.

Arrow, K.(1962), “Economic Welfare and the Allocation of Resources for Inventions”, in *The Rate and Direction of Inventive Activity*, Princeton University Press.

Andrews, F. (1979), “*Scientific Productivity: The Effectiveness of Research Groups in Six Countries”*, Cambridge University Press.

Barro, R. (1991), “Economic Growth in a Cross-Section of Countries”, *Quarterly Journal of Economics*, 106: 407-444.

Barro, R., Mankiw, N. and X. Sala-i-Martin, (1995) “Capital Mobility in Neoclassical Models of Growth”, *American Economic Review*, 85(1): 103-115.

Brynjolfsson, E. and L. M. Hitt, (1995) “Information Technology as a Factor of Production: The Role of Differences among Firms”, in *Economics of Innovation and New Technology,* 3: 183–99.

Cameron, G. and J. Muellbauer (1996), “Knowledge, Increasing Returns, and the UK Production Function”, In: Mayes, D. (ed.), *Sources of Productivity Growth in the 1980s*, Cambridge: Cambridge University Press.

Cobb, C.W. and P.H. Douglas (1928), “A Theory of Production”, in *American Economic Review*, 18: 139-165.

Denison, E. (1985), “*Trends in American Economic Growth”,* Washington: Brookings Institution.

Fabricant, S. (1954), “Economic Progress and Economic Change”, 34th Report of the National Bureau of Economic Research , New York: NBER.

Foster, R.N. (1985), ”Improving the Return on R and D”, in *Research Management*, no.1.

Griliches, Z. (1958), “Research Costs and Social Returns: Hybrid Corn and Related Innovation”, in *The Journal of Political Economy*, 5: 419-431.

Griliches, Z. (1979), “Issues in Assessing the Contribution of Research and Development to Productivity Growth**”**, in *Bell Journal of Economics,* 10: 92–116.

Griliches, Z. (1980), “Returns to R&D Expenditures in the Private Sector”, In: Kendrick, K.W. and Vaccara, B. (eds.), *New Developments in Productivity Measurement,* Chicago University Press.

Griliches, Z. (1980), “R&D and the productivity slowdown”, *American Economic Review,* 70: 343-348.

Griliches, Z. (1988), “Productivity Puzzles and R&D: Another Non-explanation”, *Journal of Economic Perspectives,* 2: 9-21.

Griliches, Z. and F., Lichtenberg (1984) “R&D and Productivity Growth at the Industry Level: Is There Still a Relationship?”, In: Griliches, Z. (ed.) *R&D, Patents and Productivity,* Chicago University Press.

Griliches, Z. and J. Mairesse (1984), “Productivity and Research Development at the Firm Level”, pp. 339-374, In: Griliches (ed.), Research and Development, Patents and Productivity, Chicago University Press.

Griliches, Z. and J. Mairesse (1998), “Production functions: The search for identification”, In: *Econometrics and economic theory in the 20th* *century: the Ragnar Frisch Centennial Symposium*, Cambridge University Press, pp.169-203.

Griliches, Z. and Ringstad, V. (1971), "*Economies of Scale and the Form of the Production Function"*, Amsterdam: North Holland.

Grossman, T.and E. Helpman (1991), "*Innovation and Growth in the Global Economy"*, MIT Press.

Hall, R. (1990), "Invariance Properties of Solow's Productivity Residual", In: Diamond, P., (ed.), *Growth/Productivity/Unemployment: Essays to celebrate Bob Solow's birthday*, Cambridge, MA: MIT Press, pp. 71-112.

Hart, A. (1966), "A Chart for Evaluating Product Research and Development", In: *Operational Research Quarterly*, 17

Hawke, G.R.(1970), *Railways and Economic Growth in England and Wales*, Oxford.

Hess, S.W. (1962), "A Dynamic Programming Approach to R and D Budgeting and Project Selection", in *IRE Transactions on Engineering Management*, 9(4).

Hicks, J.R. (1932), *The Theory of Wages*, Second Edition (1963), St Martin's Press, New York.

Jorgenson, D. (1990), "Productivity and Economic Growth", in Berndt, E. and Triplett, J. *Fifty Years of Economic Measurement*, Cambridge, MA: NBER, pp. 19-118.

Kaldor, N. and J. Mirrlees (1962), "A New Model of Economic Growth", *Review of Economic Studies*, pp. 174-245.

Kiefer D.M. (1964), "Winds of Change in Industrial Chemical Research", in *Chemical and Engineering News*, 42: 88-109.

Lichtenberg, F., R. (1995), "The Output Contributions of Computer Equipment and Personal: A Firm-Level Analysis.", in *Economics of Innovation and New Technology* No.3, pp. 201–217.

Lucas, R. (1988), "On the Mechanics of Economic Development", in *Journal of Monetary Economics*, 22 (1): 3-42.

Mairesse, *J*. (*1978*), "New estimates of embodied and disembodied technical progress", in *Annales de l'INSEE*, 30-31: 681-720.

Mansfield, E. (1971), "Social and Private Rates of Return from Industrial Innovations", in *Quarterly Journal of Economics*, vol.91.

Mansfield, E. (1980), "Basic Research and Productivity Increase in Manufacturing", *American Economic Review*, 70: 863-73.

Matthews, R.C.O., Feinstein, C. and J. Odling-Smee (1982), *British Economic Growth 1856-1973,* Oxford.

Muellbauer, J. (1986), "The Assessment: Productivity and Competitiveness in British Manufacturing", *Oxford Review of Economic Policy*, 2(3): 1-25

Nadiri, M. (1980), "Sectoral productivity slowdown", *American Economic Review*, 70: 349-355.

Romer, P., M. (1986), "Increasing Returns and Long-run Growth", Journal of Political Economy, 94(5): 1002-1037.

Romer, P., M. (1990), “Endogenous Technological Change”, *Journal of Political Economy,* 98: S71-S102.

Romer, P., M. (1993), “Implementing A National Technology Strategy with Self-organizing Industry Investment board”, *Brookings Paper on Economic Activity: Microeconomics*.

Scherer, F.M. (1971), “*Industrial Market Structure and Economic Performance*”, Chicago: Rand McNally.

Scherer, F. (1982), “Inter-industry technology flows and productivity growth”, *Review of Economics and Statistics*, 64: 627-34.

Schmidt, G. (1997), “Dynamic analysis of a Solow-Romer model of endogenous economic growth”, Working paper no.68, COPS.

Schumpeter, J., A. (1939), *Business Cycles: A Theoretical, Historical and Statistical Analysis of Capitalist Processes,* New York: Macmillan.

Solow, R. (1957), “Technical Change and the Aggregate Production Function”, *Review of Economics and Statistics*, 39: 312-20.

Stoneman, P. and N., Francis (1994), “Double Deflation and the Measurement of Output and Productivity in UK Manufacturing, 1979-1989”, in *International Journal of the Economics of Business*, 1: 423-437.

Stigler, G. (1947), “*Trends in Output and Employment”*, New York: NBER.

Stiglitz, J. (1992), “Endogenous Growth and Cycles”, Stanford University Working Paper.

Terleckyj, N. (1974), “Effects of R&D on the Productivity Growth of Industries: An Exploratory Study”, Washington DC: National Planning Association.

Tinbergen, J. (1942), “Zur Theorie des Langfristigen Wirtschaftsentwicklung”, reprinted in Tinbergen, J. (1959) *Selected Papers,* Amsterdam.

Zaman, G., Goschin, Z., Pârþachi, I and C. Herþeliu (2007), “The Contribution of Labour and Capital to Romania’s and Moldova’s Economic Growth“, *Journal of Applied Quantitative Methods*, 2(1): 176-185.

Zaman, G. and Z. Goschin (2007a), “Analysis of Macroeconomic Production Functions for Romania. Part one- the time-series approach”, in *Economic Computation and Economic Cybernetics Studies and Research*, 41(1-2): 31-46.

Zaman, G. and Z. Goschin (2007b), “Analysis of Macroeconomic Production Functions for Romania. Part two - The cross-section approach”, in *Economic Computation and Economic Cybernetics Studies and Research*, 42(3-4): 23-32.