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► **To cite this version:**

Mario Coccia. Public and Private Investment in R&D: Complementary Effects and Interaction with Productivity Growth. *European Review of Industrial Economics and Policy* , 2010, 1. hal-03468720

HAL Id: hal-03468720

<https://hal.science/hal-03468720v1>

Submitted on 7 Dec 2021

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Public and Private Investment in R&D: Complementary Effects and Interaction with Productivity Growth

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The purpose of this paper is to analyse the relationship between public and private research expenditures since it can provide important information to policy makers to improve the economic performance of country. Data from Eurostat are used. The methodology applies econometric models based on regression analyses. The main results are as follows: Public R&D expenditure is a complement for private R&D expenditure but the latter has to be higher than the former to be a determinant of a country's productivity growth. These results can be affected by several factors concerning the structure of National Systems of Innovation and Triple helix mechanisms. In addition, this research shows that the composition of public and private investment in research depends on the level of a country's development.

Research Funding; Productivity Growth; Comparative Study; Complementary Effects; Research Policy

This article has been originally published as:
Mario Coccia, 2008, Investimento pubblico e privato in R&S: complementarità ed interazione con la crescita della produttività, *Economia e Politica Industriale*, vol. 35 n. 3, pp. 127-154.

1. Introduction

Nowadays, scientific research and innovation take up considerable economic and human resources that contribute to the accumulation of intangible capital, on which modern long-term economic growth is based. Several econometric studies confirm the positive influence of Research & Development (R&D) expenditure on the growth of factor productivity (Mairesse and Sassenou, 1991; Amendola *et al.*, 1993; Hall and Mairesse, 1995; Guellec and van Pottelsberghe de la Potterie, 2001; OECD, 2003), even though several studies show that its contribution is insignificant (Bartelsman, 1990; Lichtenberg and Siegel, 1991; Griliches, 1995; Hall, 1996). The governments' new industrial policies encourage firms to invest resources in the production of inventions and new technical-scientific discoveries by means of grants and tax credits, in order to improve the competitiveness of the country system (Porter, 1985; 1990). Brécard *et al.* (2006) show that, by means of a multiplying effect, growth is actually driven by R&D expenditure. Research produces its effects by generating two forms of innovation: an increase in factor productivity (Bartelsman and Doms, 2000) and an improvement in the quality of products (Saviotti, 1985), thus boosting aggregate demand as a consequence of the drop in costs and prices, resulting in the growth of the economic system.

Moreover, the increase in scientific production and innovations depends on an efficient national innovation system (Lundvall, 1992; Patel and Pavitt, 1994) and on the Triple Helix mechanism (Etzkovitz, 2006), financed by adequate national economic-financial resources. Therefore, policy-makers must decide how much and how to invest in R&D in order to encourage the creation of inventions and the fluidity of technology transfer, which are increasingly necessary to modern economic growth (Coccia, 2004).

In other words, in order to be efficient and effective, new industrial policies must provide precise answers to the following questions: does public financing of research influence the private level of investment in R&D? Is public investment in R&D a complement or a substitute for private investment in R&D? How do these two types of R&D investment contribute to the productivity growth of the economic system?

The purpose of this paper is to provide answers to the above questions by analysing the relationship between public financing, by the Government, and private financing, by firms, in the field of R&D as well as their interaction with productivity growth. Before tackling this issue, let me introduce the theoretical framework and explain the methodology that make up the basic structure on which this research is founded.

2. Background

Several econometric studies examine whether public investment in R&D is a complement or a substitute to private investment (Blank and Stigler, 1957). However, despite the large amount of scientific literature, results are rather ambiguous. A number of empirical studies show that public financing has spillover effects on private investments in R&D (Jaffe, 1989; Adams, 1990; Toole, 1999). Knowing the sign of the relationship between public and private financing in R&D is important because, in the case of complementarity between the two types of investment, the subsidisation of private investment in R&D at the expense of the tax-payers' community is justified. In contrast, it is much harder to justify such investments at the expense of society if there is a substitution effect between public and private investment in R&D. Several studies dealing with this topic focus on private firms, on the industrial sector, and, to a lesser extent, on aggregate analyses at the country level. Despite the fact that empirical studies at the micro and macro level show that there is complementarity between the two types of investment, no definitive answer have yet been provided, especially at the aggregate level. The ambiguity of results derives from the differences among the analysed periods, sectors, and countries. The objective of *policy makers* is to improve the conditions for the generation of economic growth both by means of efficient allocation of public resources to R&D and by adopting policies that stimulate public as well as private labs to produce both basic and applied research.

The core issue discussed here concerning the complementarity or substitution of public and private investments in the field of R&D has led several scholars to carry out analyses at the firm level (Higgins and Link, 1981; Link, 1982; Toivanen and Niininen, 1998; Busom, 1999 and Wallsten, 1999; Duguet, 2003; Lööf and Heshmati, 2005), at the sector level – see, for example, the studies by Levin and Reiss (1984), and Lichtenberg (1984) – and at the aggregate level. David *et al.* (2000) consider some macro and micro economic studies and find a prevalence of complementarity between public and private investments in the field of research. In particular, if the firm aggregation level is used (Toivanen and Niininen, 1998), 18 out of 38 cases are in favour of a clear substitution of public investment in research over private investment, while at the sector level (Adams, 1998; Toole, 1999) 4 cases out of 28 display a substitution effect. Since this paper analyses data at the aggregate level, the latter aspect is further investigated.

Levy and Terleckyj (1983) carry out the first macro level study on the relationship between public and private financing to research. Their main findings are that R&D contracts financed by the government are positively and significantly associated with private R&D investments and firms' productivity. Levy and Terleckyj also find that an

additional dollar of public R&D contract, added to the stock of R&D financed by the government, has the effect of increasing private R&D investments by 27%. Lichtenberg (1987) claims that a higher R&D intensity in public research labs does not generate an additional impact from public research expenditure on private investment. Robson (1993) finds that the level of public investment in R&D has a positive impact on private investment. Diamond (1998) draws the same conclusions. Kealey (1996) uses historical analyses of R&D investments in different countries and shows that a higher level of public investment in research relative to private investment reduces more than proportionally the level of national investment in R&D. Other studies show that the relationship between public and private investment in basic research is characterised by complementarity rather than substitution, but none of these studies use instrumental variables to control the influence of the business cycle (David *et al.*, 2000). There have been some recent attempts to analyse the relationship between public and private investment in research using time-series observations for some OECD countries. For example, Levy (1990) uses a sample of 9 countries for the period of 1963-1984 and regresses private R&D investment on public R&D investment, distinguishing among three geographical areas. Levy (1990) finds that 5 countries exhibit a complementarity relationship between public and private R&D investment, whereas two countries show substitution effects. The reason for these differences remains unexplained. Von Tunzelmann and Martin (1998) use a panel data and a linear model: in only 7 of the 22 countries do they find that changes in government-funded R&D have any significant impact on changes in industry-funded R&D. They show that in 11 case studies out of 33 there is a substitution effect of public for private R&D investment.

Moreover, there is an extensive literature that studies how public and private R&D investments influence the productivity of countries (Department of trade and industry-DTI, 2006). Lichtenberg and Siegel (1991) and Hall and Mairesse (1995) provide indications of the correlation between R&D and productivity. Amendola *et al.* (1993) present well-documented evidence that R&D has noticeable effects on the growth of both productivity and competitiveness. According to Brécard *et al.* (2006), R&D produces effects on aggregate productivity gains. Griffith *et al.* (2004) claim that R&D has a direct effect on the growth of Total Factor Productivity (TFP) in a panel of sectors for 12 OECD countries. Grossman and Helpman (1991) show that spillovers from R&D are an important source of growth. Aghion and Howitt (1998) claim that R&D causes productivity growth, which in turns raises GDP. Zachariadis (2004) uses aggregate data from the manufacturing sector for a group of 10 OECD countries referring to the 1971-1995 period and finds that research and development intensity has a positive impact on the growth rates of both productivity and GDP. Lastly, Zachariadis (2004), Guellec and van Pottelsberghe de la Potterie (2004) investigate the relationship between TFP and R&D and conclude that there is a positive relation between these two variables, whereas in his paper Zachariadis (2003) rejects the null hypothesis that growth is not induced by R&D in favour of Schumpeter's endogenous growth models.

The present imperfect state of the economic literature does not lead to conclusive results in relation to both the sign and the intensity of the relationship between public and private research expenditure and how R&D influences productivity growth. In particular, despite being very important for economic policy decisions, the aggregate level analysis of the relationship between public and private research investments and

their interactions with productivity growth has not been adequately investigated. This leads to further investigations using new perspectives, new data sets and other econometric techniques, as explained by David, Hall and Toole (2000), in order to provide insights on this important aspect that drives the modern economic growth of countries.

3. Research methodology

This research uses the Eurostat database (2007), which includes some economic and technological indicators for a number of countries in relation to the 1990s and the early years of 2000s. In particular, the research uses the indicators of 31 countries and five macro areas, comprising the European Union with 12, 13, 15, 25, and 27 countries over a period of 10-12 years. Table 1A in the Appendix describes the variables (displayed with their acronyms), as well as the countries and the periods. The data are analyzed first by means of descriptive statistics and then by using econometric linear regression models (Girone and Salvemini, 1988; Verbek, 2005). The statistical analysis is preceded by an operation of horizontal and vertical data cleaning, to ensure the correct application of an econometric analysis of the parametric type. The normal distribution of the variables is checked by means of descriptive statistics and asymmetry and skewness indexes, as well as by applying the normal Q-Q plot and the Kolmogorov-Smirnov and Shapiro-Wilks normality tests, using the statistics software SPSS (Statistical Package for the Social Sciences).

The base model is the following (for the abbreviations, see table 1A in the appendix):

$$R\&DBUSS_t = f(R\&DGOV)_{t-1}$$

The applied model is a dynamic linear simple regression model of the *leading indicator model* type, which represents a special type of the dynamic regression model (Hendry and Richard, 1982; Spanos, 1986):

$$y_{it} = \beta_0 + \beta_1 x_{it-1} + \varepsilon_{it}$$

[1]

$$R\&DBUSS_{it} = \beta_0 + \beta_1 R\&DGOV_{it-1} + \varepsilon_{it}$$

where the *i* subscript indicates the country and *t* the time.

The specification of the model has a lagged explanatory variable, because R&D is a dynamic process and countries do not adapt immediately to the long period levels due to the adjustment of costs and other factors (van Reenen, 1997). Furthermore, since the direction of causality between R&D expenditure by the firms and by the government can be bidirectional, using a *lag* is not sufficient to eliminate endogeneity problems and I also use the *two-stage last-squares-2SLS* method.

Stage I:

The R&D expenditure by the government (R&DGOVEDU) is a function of the per capita Gross Domestic Product (GDP) of the countries (GDPPS) and of the real GDP growth rate (GROWTHGDP), which are indicators of economic growth.

$$R\&DGOVEDU_{it} = \beta_0 + \beta_1 GDPPS_{it-1} + \beta_2 GROWTHGDP_{it-1} + \varepsilon_{it}$$

[2]

Since GDPPS and GROWTHGDP have important direct effects on private R&D, in stage II, the error of the stage I regression $\varepsilon_{i,t}$ is used. The estimated error represents the component of public R&D growth not explained by GDP per capita and GDP growth and ascribable to research and innovation policies as well as to the organisation of the national innovation system (Lundvall, 1992) and to the functioning of the Triple Helix mechanism (Etzkowitz and Leydesdorff, 2000). Moreover, in stage II, besides the estimated error, per capita GDP and GDP growth can be used as predictors.

The regressions are performed using the Prais-Winsten estimation method, in order to overcome the problem of autocorrelation and to correct the values of the Durbin-Watson test, so that more robust estimates of the parameters can be achieved.

Stage II:

$$R\&DBUSS_{it} = \beta_0 + \beta_1 Err_I_Stage_{it-1} + \beta_2 GDPPS_{it-1} + \beta_3 GROWIHGDP_{i,t-1} + \varepsilon_{it}$$

The above model makes it possible to provide an answer to the following question: is the relationship between -the increase in R&D public expenditure due to research and innovation policies and an efficient national innovation system (Err_I_Stage)- and -private R&D expenditure (R&DBUSS)- characterised by a substitution or a complementarity effect? The last equation indicates both the sign and the magnitude of this effect.

A second model makes it possible to analyze the relationship between research expenditure and relative productivity growth in the countries (LPRH, the other variable acronyms are in table 1A in the Appendix). The model is:

$$y_{it} = \beta_0 + \beta_1 x_{it-1} + u_{it}$$

[3]

$$LPRH_{it} = \beta_0 + \beta_1 (R\&DBUSS - R\&DGOVEDU)_{it-1} + u_{it}$$

Considering that in this situation too the direction of causality can be bidirectional, a model based on two-stage last-squares method (2SLS) is applied like in the previous case.

Stage I:

The difference between R&D expenditure by firms (R&DBUSS) and by the government (R&DGOVEDU) is a function of the GDP per capita of the countries (GDPPS) and of the relative GDP growth rate (GROWTHGDP), two indicators of economic growth.

$$R\&DBUSS - R\&DGOVEDU_{it} = \beta_0 + \beta_1 GDPPS_{it-1} + \beta_2 GROWIHGDP_{i,t-1} + u_{it}$$

[4]

Stage II:

$$LPRH_{it} = \beta_0 + \beta_1 Err_I_stadio_{it-1} + \beta_2 GDPPS_{it-1} + \beta_3 GROWIHGDP_{i,t-1} + \varepsilon_{it}$$

[5]

The above model makes it possible to see whether and how the growth in the difference between private and public R&D expenditure (R&DBUSS_GOVEDU), due to an efficient national innovation system, improves productivity (LPRH) and, as a consequence, contributes to the economic growth of the countries. Lastly, the stability of the parameters over time is checked by the Chow test.

4. Empirical study and analysis

The Kolmogorov-Smirnov and Shapiro-Wilks normality tests as well as the kurtosis and skewness coefficients show the normality of distribution of the variables (Table 2A in the Appendix), which makes it possible to correctly apply both the interdependence and the dependence analyses. The analyses are performed by using the statistics software SPSS and summarised in the following tables.

Table 1 shows a strong positive correlation between R&D expenditure by firms and by the government – with values higher than 75% –, whereas the partial correlation (table 2) between the two above-mentioned variables, referring to both GDP per capita and GDP growth rate, is still high and equal to 65.3%.

Tab. 1 – Correlations

| | | R&DBUSS 99_05 | R&DGOV_EDU 98_05 | GROWTHGDP 97_04 | GDPPS 97_04 | LPRH 99_05 |
|-----------------|-----------------|------------------|---------------------|--------------------|----------------|---------------|
| R&DBUSS99_05 | Pearson | 1.00 | 0.76** | -0.28** | 0.75** | 0.72** |
| | Correlation | | | | | |
| | Sig. (2-tailed) | | 0.00 | 0.00 | 0.00 | 0.00 |
| | N | 163 | 163 | 163 | 163 | 163 |
| R&DGOV_EDU98_05 | Pearson | 0.76** | 1.00 | -0.24** | 0.51** | 0.48** |
| | Correlation | | | | | |
| | Sig. (2-tailed) | 0.00 | | 0.00 | 0.00 | 0.00 |
| | N | 163 | 163 | 163 | 163 | 163 |
| GROWTHGDP97_04 | Pearson | -0.28** | -0.24** | 1.00 | -0.20** | -0.23** |
| | Correlation | | | | | |
| | Sig. (2-tailed) | 0.00 | 0.00 | | 0.01 | 0.00 |
| | N | 163 | 163 | 163 | 163 | 163 |
| GDPPS97_04 | Pearson | 0.75** | 0.51** | -0.20** | 1.00 | 0.93** |
| | Correlation | | | | | |
| | Sig. (2-tailed) | 0.00 | 0.00 | 0.01 | | 0.00 |
| | N | 163 | 163 | 163 | 163 | 163 |
| LPRH99_05 | Pearson | 0.72** | 0.48** | -0.23** | 0.93** | 1.00 |
| | Correlation | | | | | |
| | Sig. (2-tailed) | 0.00 | 0.00 | 0.00 | 0.00 | |
| | N | 163 | 163 | 163 | 163 | 163 |

** Correlation is significant at the 0.01 level (2-tailed)

Tab. 2 – Partial correlations

| Control Variables | | R&DBUSS99_05 | R&DGOV_EDU98_05 |
|-------------------|-------------------------|--------------|-----------------|
| R&DBUSS99_05 | Correlation | 1.000 | 0.653 |
| | Significance (2-tailed) | - | 0.000 |
| | Df | 0.000 | 159 |
| R&DGOV_EDU98_05 | Correlation | 0.653 | 1.000 |
| | Significance (2-tailed) | 0.000 | - |
| | Df | 159 | 0.000 |

The econometric analysis of the regression models is summarised in Table 3. The endogeneity of the model is reduced by using both lagged independent variables and the 2SLS method through an auto-regressive estimation procedure of the regression coefficients from time series with autocorrelated errors of the first degree (Prais-Winsten estimation method), in order to eliminate the serial correlation of the variables, thus obtaining more robust estimations of the parameters. The results are good and the parameters are meaningful at the 1% and 5% level. The R^2 adjusted shows, in the final phase of the models, values higher than 70%, which prove a high degree of goodness of fit in explaining the relationship between the variables. The Durbin-Watson test (DW), after applying the Prais-Winsten method, indicates lack of autocorrelation.

Tab. 3 – Parametric estimations of the linear regression dynamic model

| Explanatory variables | Model 1 (2SLS) | | Model 2 (2SLS) | |
|-------------------------------|---------------------|----------------------|----------------------------|------------------|
| | Dependent variable | | Dependent variable | |
| | $x_{i,t} = R\&DGOV$ | $y_{i,t} = R\&DBUSS$ | $j_{i,t-3} = R\&DBUSS-GOV$ | $w_{i,t} = LPRH$ |
| | Stage 1 | Stage 2 | Stage 1 | Stage 2 |
| $z_{i,t-1} = GDPPS$ | 0.003*** (0.000) | 0.013*** (0.001) | 0.010*** (0.001) | 0.783*** (0.025) |
| $k_{i,t-1} = GROWTHGDP$ | -0.015** (0.006) | -0.038*** (0.012) | -0.021* (0.011) | -0.483 (0.391) |
| $\epsilon_{i,t} = ErrR\&DGOV$ | - | 1.413*** (0.145) | - | - |
| $u_{i,t} = ErrR\&DBUSS-GOV$ | - | - | - | 5.250* (2.752) |
| Constant | 0.301*** (0.046) | -0.187** (0.093) | -0.535*** (0.092) | 8.675*** (3.166) |
| R^2 adjusted | 0.37 | 0.73 | 0.55 | 0.86 |
| Durbin-Watson | 1.97 | 1.94 | 1.94 | 2.00 |
| N. cases | 163 | 163 | 163 | 163 |

*** value is significant at the 0.001 level; ** value is significant at the 0.05 level; * value is significant at the 0.01 level

Note 1: Estimation by 2SLS and the autoregression procedure estimates true regression coefficients from time series with first-order autocorrelated errors. Standard error in parenthesis

$x_{i,t}$ = R&DGOV: R&D expenditure Government 1998 2005

$z_{i,t-1}$ = GDPPS: GDP per Capita in PPS EU27=100 (1997-2004),

$k_{i,t-1}$ = GROWTHGDP: Growth rate of GDP volume (1997-2004)

$y_{i,t}$ = R&DBUSS: R&D expenditure Business enterprises 1999-2005

$j_{i,t-3}$ = R&DBUSS-GOV: R&D expenditure Business enterprises minus R&D expenditure Government 1998-2005

$w_{i,t}$ = LPRH: Labour productivity per hour worked 1999 2005

$u_{i,t}$ = ErrR&DBUSS GOV: Error R&D expenditure Business – Government 1998 2005

$\epsilon_{i,t}$ = ErrR&DGOV: Error R&D expenditure Government 1998 2005

Note 2: Investment in R&D includes is formed by public investment in research (GOV) and education (EDU);

i subscript is the country, t subscript is the time.

The second equation of Model 1 shows that an increase by 1 percentage point in public R&D expenditure (due to research and innovation policies, the organisation of the national innovation system, and the efficient functioning of the Triple Helix mechanism) corresponds to an increase in private R&D expenditure by 1.41%.

Table 2A, confirmed by the Chow test, displays stability of the parameters in time (R&D expenditure Business Enterprise and R&D expenditure Government). In particular, in the period of 2001-2005 the net impact of public R&D expenditure on private expenditure decreased in comparison to the previous period (1997-2000) from 3.91 to 3.18, probably due to the not very favourable economic trend, reflected by the low average GDP growth rate, which was 2.74 in the last period compared to 4.01 during the previous period (1997-2000).

The above-mentioned results of correlations and regression analysis can be summarised in the following propositions:

Proposition 1

The increase in public R&D expenditure due to research and innovation policies tends to be complementary to private R&D investments, thus producing spillover effects.

Proof

The second regression line of model 1 (Table 3) proves that an increase by 1 percentage point in public R&D expenditure, due to efficient research and innovation policies, corresponds to an increase in R&D investments by firms by 1.41 (*spillover effect*). The determination index shows that over 73% of the variability of private R&D investment levels is due to the linear dependence of the component represented by public R&D expenditure, thanks to efficient research and innovation policies.

Table 2A displays another important result. The countries are divided into three groups:

countries with high level of GDP per capita > 100.00 (EU27=100) and productivity > 100 (EU15=100);

countries with average GDP per capita and productivity, values between 50 and 100;

countries with low GDP per capita and productivity, values lower than 50.

These typologies can be associated with three groups of countries, precisely having *high*, *average*, and *low* levels of development. In the *high* development group, R&D investments by firms are much higher than public investment (1.39 vs. 0.70); the total magnitude of national R&D expenditure is 2.09.

In the second group (*average*) there is a balance between the two types of investment (0.44 vs. 0.42). The total magnitude of national R&D expenditure is 0.86 (average of the 1998-2005 period).

Lastly, in the countries having a *low* level of development the government's R&D expenditure is much higher than the firms', probably because the industrial structure is not developed enough to be able to afford high private R&D investments (0.25 < 0.39); the total magnitude is lower than in the other two groups.

The different behaviour displayed by the third group (*low*), in comparison to that of more advanced countries, reflects a low value of productivity and GDP per capita in time. The indicators at the level of countries are summarised in table 3A (in the Appendix), which displays average values in time. A special remark should be made about Italy: despite being a country with *high* GDP per capita, the total magnitude of national R&D expenditure is similar to that of countries with *average* GDP per capita, and the ratio between public and private R&D expenditure is similar to that of countries with *low* GDP per capita. The macroeconomic effect of this behaviour has led across time to a low average growth rate, as the following figures also confirm.

This result, together with those provided by the econometric analysis in table 3 (model 2), clearly shows that a positive difference between R&D expenditure by the firms and by the government has a positive influence on the productivity growth of the economic system. Thus, the following proposition is given:

Proposition 2

The growth of the component represented by the difference between private and public R&D, due to appropriate research and innovation policies together with an efficient national innovation system and functioning of the Triple Helix, has a positive impact on the country's Labour productivity per hour worked.

Proof

The second regression line of model 2 (Table 3) proves that increasing by one unit the component that includes the difference between R&D expenditure financed by the firms and by the government (not explained by GDP per capita and growth rate) causes an increase in productivity by about 5.25 per cent (values of the countries expressed in EU15=100). The coefficient of determination shows that over 86% of the variability of the countries' labour productivity per hour worked is due to the linear dependence of the component represented by the difference between private and public R&D expenditure, thanks to appropriate research and innovation policies together with an efficient national innovation system and functioning of the Triple Helix.

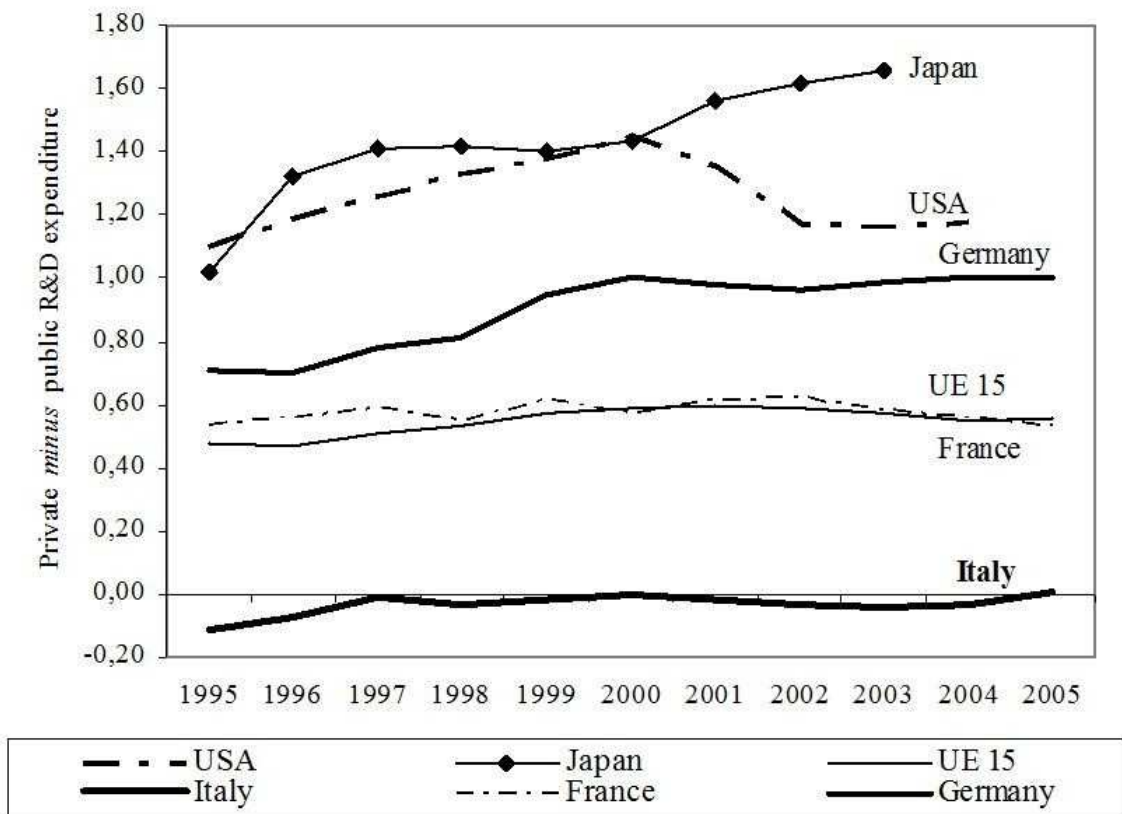
These results, together with the geometrical representation of the variables, lead to some interesting remarks on the countries under investigation and on Italy in particular.

Figure 1 displays the behaviour of private and public R&D expenditure (difference between the two indicators) in the United States, the 15-country European Union, and Japan (the so-called *G3-Group of Three*) as well as in other industrialised countries. The G3-area analysis is important because it is believed that the world's economic growth is led by these three large macro subjects (Torrise, 2000). The time dynamics confirm that

in the G3-area there is a prevalence of private R&D expenditure over public expenditure (trend in the positive quadrant of the x -axis and the y -axis). At the European level, if other large countries are considered, Germany and France clearly display the same behaviour as the G3-area countries, whereas Italy displays the opposite behaviour, similar to that of countries with a low development level (see also table 3A).

In fact Italy is the only country, among all industrialised countries, in which not only the value of national R&D expenditure is low (Tab. 3A) but the difference between private and public R&D investment in the 1995-2005 period is negative (trend under the x -axis in figure 1!).

Fig. 1 – Private minus public R&D expenditure over time per country



This result, when related to figures 2 and 3, makes it clear that Italy was the only country with a striking decline in its labour productivity per hour worked and consequently in its GDP per capita, which was amplified in comparison to the other countries by the adoption of the common currency (i.e. Euro) in 2001. The situation triggered a spiral of marked reduction in competitiveness of the firms and of the overall Italian economic system, unprepared for the new European and worldwide scenarios.

Fig. 2 – Labour productivity per hour worked over time per country

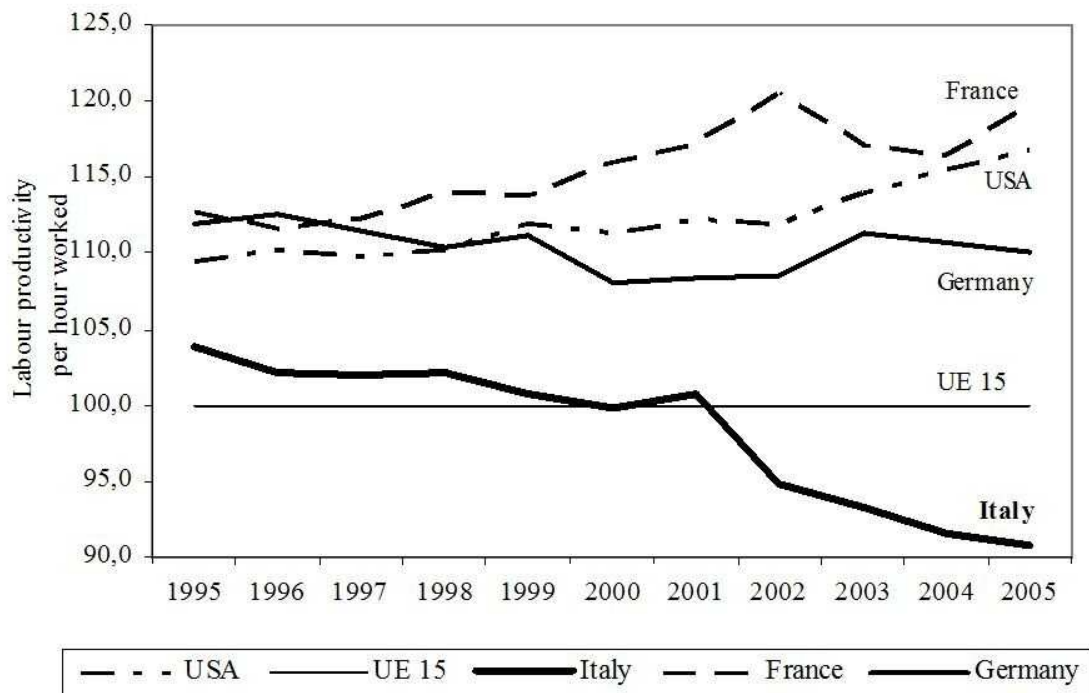
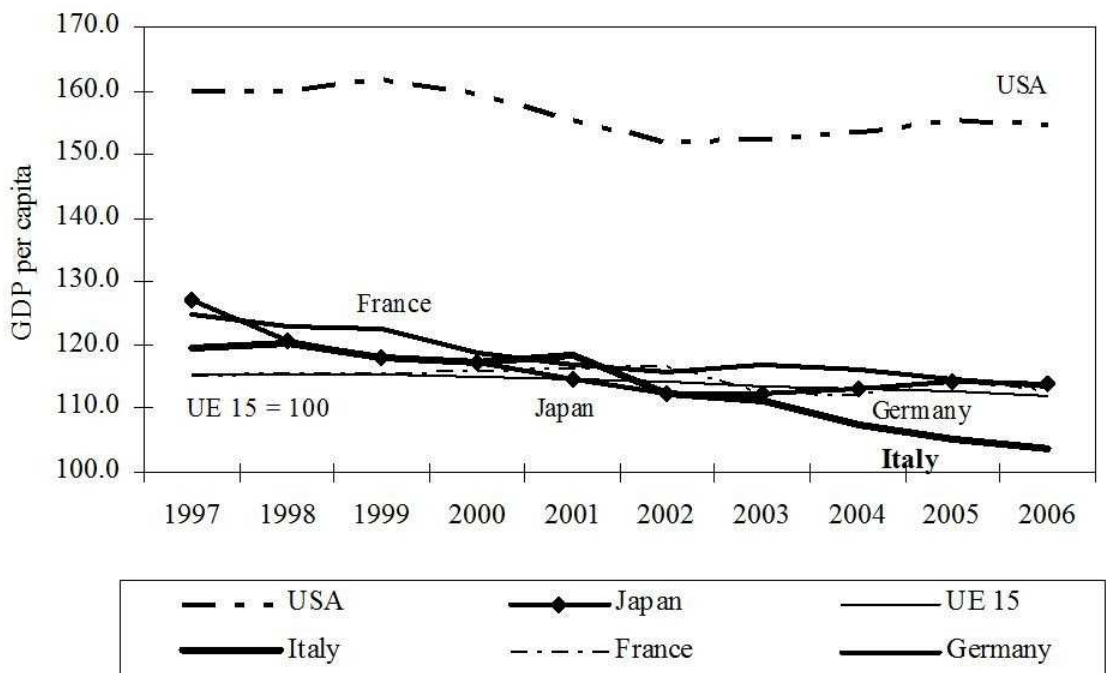


Fig. 3 – GDP per capita dynamics over time per country



5. Lessons learned and concluding remarks

The lessons learned from this research are the following:

The relationship between public expenditure in research and innovation and private expenditure in R&D by firms is characterised by complementarity, which produces *spillover* effects.

Public R&D expenditure must be lower than private R&D expenditure in order to have a positive impact on the country's productivity growth.

Countries with a high development level (high GDP per capita) have a trend of higher private R&D investments (as percentage of the GDP) in comparison to public investments,

whereas less developed countries (low GDP per capita), which have a weak economic and industrial structure, have a higher public R&D expenditure in comparison to private R&D investments.

These results are in line with the economic literature, which usually regresses private R&D financing on public financing, using some control variables; if the coefficient is positive, there is a complementarity effect, otherwise there is substitution. Generally speaking, some studies consider the magnitude of the regression coefficient to say that a dollar of public financing increases or decreases private R&D investment by x . Nevertheless, the results available in the literature are often not univocal. For example, Wallesten (1999) gives evidence of a crowding-out effect, whereas Robson (1993) claims that there is *one-to-one* complementarity. Blank and Stigler (1957) use a sample of firms to show that there is a substitution effect, but by changing the sample they find a complementarity effect. Moreover, small and medium enterprises often tend to use public R&D financing as a replacement of their internal resources, while large enterprises try to achieve synergetic complementarity effects of the *pump-priming* type between public and private resources. A large number of studies on the substitution or complementarity effect in firms and in various industrial sectors were carried out using data on the USA (21 studies out of 33, see David *et al.*, 2000), a country that has a specific national innovation system (Lundavall, 1992) characterised by high levels of funding to military R&D. According to David *et al.* (2000), one third of the case studies at the firm, sector, and aggregate levels provide evidence of a substitution effect of public research expenditure and private investments.

It would be very important to understand the circumstances that lead some public R&D investments to crowd out private investments. In any case, it should be noted that there are latent variables, linked to socio-economic and environmental factors, which can influence the firms and the government in their decisions concerning R&D investments. A complete analysis of the substitution or crowding out effect of R&D expenditure is necessarily related to the understanding of the decision mechanisms used by public bodies (governments and departments) and private subjects (e.g. firms). It is also essential to understand how the national innovation system and the Triple Helix mechanism operate, as these can increase or decrease the production and the absorption of technical-scientific knowledge.

This research confirms, at the aggregate level, the complementarity between public research expenditure and private R&D investment but it is important for the Government to have a level of public R&D expenditure, as part of the total GDP, lower than that of firms in order to drive productivity and economic growth in the long run.

What can be the underlying causes of a net complementarity effect?

David and Hall (2000) show that, in the relationship between public and private R&D financing, complementarity dominates over substitution if the following four conditions are true:

a) the relative size of the public sector in total R&D input is small; *b)* the elasticity of the labour supply of qualified personnel is high; *c)* the public grant–contract mix for R&D is skewed more towards the first research policy instrument; and lastly *d)* the rate of private marginal yield of R&D decreases more than proportionally with increased R&D expenditures.

Moreover, David and Hall (2000) claim that an increase in public R&D demand, whenever the supply of R&D inputs is infinitely elastic –as is likely to be in the short-run– crowds out private R&D expenditure, while in the opposite case it generates spillovers. In particular, a policy of growing public financing to R&D increases the

prices of the inputs needed by R&D and, as a consequence, the costs associated with potential private R&D projects, capable of causing, *ceteris paribus*, a reduction in the level of private research investments. Simultaneously, the additional public investment in research produces higher returns of R&D projects together with higher training of new scientists and engineers, thus acting as *demand-driven*. In short, the long-term dynamic balance of public R&D investment tends to cause a net complementarity effect rather than crowding out of public for private research. This effect has a positive impact on productivity and on national economic growth *if, and only if*, the level of public R&D expenditure is lower than private expenditure and the former is mainly targeted to stimulating firms to invest in R&D, rather than financing public labs.

The research shows that future economic growth will be increasingly based on effective policies of research financing and of management of the national innovation system and the Triple Helix, in order to improve the innovation capabilities of firms, networks, sectors, and of the economy as a whole. At the international level, a strong convergence of science and technology policies is emerging. In Europe, the US, and Japan, the focus has been on pre-competitive R&D collaborations; with emphasis on *New technology based firms*; encouragement of venture capital (Lerner, 2002), as well as technology transfer and *science parks* (Dodgson and Bessan, 1996; Tassej, 1997). Despite this convergence, the countries' economic performance is different. This paper confirms that there is complementarity between public and private R&D expenditure, *if and only if* public R&D financing is targeted to stimulating private financing. If public financing is allocated mainly to universities and public labs, there can be a crowding out effect (Lichtenberg, 1987) with total reduction of the national R&D expenditure (Kealey, 1996). Public research labs perform a variety of functions but it is industrial research labs that play a key role in improving competitiveness. A large portion of economic resources should therefore be allocated to industrial research, to the detriment of public labs. One of the advantages of industrial labs is their proximity to manufacturing processes, which helps the transformation of scientific knowledge into new products. Industrial research labs can better evaluate financial risks and returns deriving from R&D investments in comparison to public labs, since they are already operating on the market (Hill, 1969; Chen *et al.*, 2006). Furthermore, resources invested in industrial research produce a wide range of benefits to business, industrial, and national competitiveness (Porter, 1985; 1990). The largest portion of public resources should drive firm labs to invest more in scientific research, whereas only a small portion should be allocated to the financing of basic research, which is characterised by uncertainties about its future commercial applications (see, for instance, aerospace and astronomy as well as many humanistic and socio-economic researches).

Therefore, in order to produce positive macroeconomic effects at a national level, public R&D expenditure should be lower than the firms' expenditure to avoid crowding out effects. Moreover, high public R&D financing can be counterproductive and increase public deficit, with negative repercussions on interest rates and on the country's future economic performances. Steil *et al.* (2002) study the technological and economic performance of different countries and find that in the USA, Japan, Germany, France, and the UK, the interventionist role of the government in the economic field has reduced in favour of that of the market forces, which have become more important in the allocation of resources within the research sector, even though several governments have not yet solved their problems regarding under-investments in basic research, which is a public good (Arrow, 1962). In 2002, the European Council directed European

countries, in line with international trends, towards an increase in national R&D investments – equal to 3% of the GDP –, 56% of which should be financed by the private sector, in order to bring the European Union to the innovation intensity and growth levels of the USA by 2010 (European Commission, 2003; 2004; 2005; Room, 2005). This objective can be achieved if the Government acts as a *referee* of the elements of the economic system, applying a range of incentives to private firms to stimulate their industrial research investments. Moreover, the Government should encourage industrial research labs to recruit scientists and engineers from universities and public labs, so that the economic system has more industrial scientists and fewer academic scientists.

The research shows high economic performances in countries with low public financing to R&D together with high investments in research by private enterprises (the UK, the USA, Germany, etc.), which are capable of investing in a much better way than the Government, the politicians, and the bureaucrats. Furthermore, figures 1-3 and A3 show low economic performance in countries (for example, Italy) whose public expenditure in R&D is higher than private expenditure¹. In brief, the research policy focusing on private investments in research that are higher than public investments increases labour productivity per hour worked and long-term economic growth. In addition, these research policies are amplified when combined with monetary stability, effective regulations, liberalisations, and competition policies managed by antitrust authorities. The final result is an increase in the purchasing power, as a consequence of cost and price reductions, triggered by technological innovations created by private R&D investments, driving the aggregate demand and the general increase in personal as well as national wealth.

The main purpose of the economic literature has always been the derive insights on the determinants of economic growth and of the wealth of nations. In the second half of the 20th Century, the discussion also concerned the criteria for the allocation of public and private economic resources to R&D activities as well as the mechanisms that create a connection between scientific production, technological production, and the creation of wealth. In the 1950s, this connection was of the *technology-push* type (linear model), in the 1960s it was of the *market-pull* type, in which innovation is driven by the market (Malerba, 2000), while in the 1970s the model became more complex by bringing together the two previous approaches into the so-called *coupling model*. The model has recently reached its fourth generation with the so-called integrated model (Rothwell, 1994). Despite having some limits, the linear model, which is the basis for this paper, is the most widely used in empirical tests thanks to its simplicity and consistency. Moreover, despite the fact that several studies see R&D as the cause of a simultaneous increase in factor growth and GDP (Aghion and Howitt, 1998; Dinopoulos and Thompson, 1998), it should be noted that the analysis of the causality relation among public and private R&D, productivity increase, and economic growth is no easy task, since it can be bi-directional and characterised by *cross-fertilisation* effects. The above-mentioned studies would benefit from considering feedback effects operating through price movement in the markets for R&D inputs on the macro level, whereas in micro-

¹ Drawing an analogy with biology, the relation between private and public investment in R&D is similar to the relation between the levels of good and bad cholesterol in the blood. High levels of good cholesterol are desirable (similarly to high levels of R&D in private firms). On the other hand, despite being present in the blood, bad cholesterol should not reach a high level – just like public expenditure on R&D – if the efficiency and the overall health of the system (biologic/economic) is to be preserved.

level analyses the findings should reflect “real” rather than nominal expenditure relationships between public and private R&D.

In conclusion, the strategy to increase a country productivity in the long run is based on public R&D expenditure that is governed by research and innovation policies complementary to those of private firms, producing *spillover* effects. However, this should be a minority portion of the total national investment in R&D, and precisely: about 32% of national R&D expenditure should stem from the government and over 57% of the expenditure should come from private firms, in order to increase productivity and, as a consequence, the wealth of the country (Coccia, 2008). The above results could be further supported by a sound theoretical framework capable of explaining the firms’ decisions concerning R&D in a better way, besides effective research and innovation policies by governments linked to the trends of the business cycle. The economic literature should investigate these aspects further in the future in order to help policy makers take appropriate decisions concerning industrial and economic policies with the purpose of favouring economic growth in modern economies.

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Tab. 1A – Variables

| Acronyms and period | Indicators | Description |
|---------------------|--|--|
| R&DTOT95_05 | Research and development expenditure: all sectors (% of GDP) | Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications. R&D expenditures include all expenditures for R&D performed within the business enterprise sector (BERD) on the national territory during a given period, regardless of the source of funds. R&D expenditure in BERD are shown as a percentage of GDP (R&D intensity). Gross domestic product (GDP) is a measure for the economic activity. It is defined as the value of all goods and services produced less the value of any goods or services used in their creation. The volume index of GDP per capita in Purchasing Power Standards (PPS) is expressed in relation to the European Union (EU-27) average set to equal 100. If the index of a country is higher than 100, this country's level of GDP per head is higher than the EU average and vice versa. Basic figures are expressed in PPS, i.e. a common currency that eliminates the differences in price levels between countries allowing meaningful volume comparisons of GDP between countries. Please note that the index, calculated from PPS figures and expressed with respect to EU27 = 100, is intended for cross-country comparisons rather than for temporal comparisons. Gross domestic product (GDP) is a measure of the results of economic activity. It is the value of all goods and services produced less the value of any goods or services used in producing them. The calculation of the annual growth rate of GDP volume allows comparisons of economic development both over time and between economies of different sizes, irrespective of changes in prices. Growth of GDP volume is calculated using data at previous year's prices. Gross domestic product (GDP) is a measure for the economic activity in an economy. It is defined as the value of all goods and services produced less the value of any goods or services used in their creation. GDP per hour worked is intended to give a picture of the productivity of national economies expressed in relation to the European Union (EU-15) average. If the index of a country is higher than 100, this country level of GDP per hour worked is higher than the EU average and vice versa. Basic figures are expressed in PPS, i.e. a common currency that eliminates the differences in price levels between countries allowing meaningful volume comparisons of GDP between countries. Expressing productivity per hour worked will eliminate differences in the full-time/part-time composition of the workforce. |
| R&DBUSS95_05 | Research and development expenditure: Business enterprise sector (% of GDP) | |
| R&DGOV95_05 | Research and development expenditure: Government sector (% of GDP) | |
| R&DEDU95_05 | Research and development expenditure: Higher education sector (% of GDP) | |
| GDPPS97_06 | GDP per capita in Purchasing Power Standards (PPS) (EU-27 = 100) Please be aware that this indicator has been rescaled, i.e. data is expressed in relation to EU-27 = 100 | |
| GROWTHGDP97_06 | Real GDP growth rate Growth rate of GDP volume - percentage change on previous year | |
| LPRH95_05 | Labour productivity per hour worked. GDP in Purchasing Power Standards (PPS) per hour worked relative to EU-15 (EU-15 = 100) | |

Countries:

Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, EU (15 countries), EU (25 countries), EU (27 countries), Euro area (12 countries), Euro area (13 countries), Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, The United Kingdom, The United States

Source: Eurostat (2007)

Tab. 2A – Descriptive statistics

| | Descriptive statistics | | | | Period | | Level of GDP per capita | | | | | | | |
|---------------------|------------------------|-----------|---------------------|---------------------|-----------|-----------|-------------------------|-----------|--------|-----------|---------|-----------|-------|------|
| | | | | | 1998-2001 | | 2001-2005 | | High | | Average | | Low | |
| | Mean | Std. Dev. | Skewness (Std. Er.) | Kurtosis (Std. Er.) | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | | |
| R&DBUSS-GOVEDU98_05 | 0.35 | 0.48 | 0.40 (0.19) | -0.50 (0.38) | 0.36 | 0.48 | 0.33 | 0.48 | 0.69 | 0.37 | 0.02 | 0.22 | -0.15 | 0.18 |
| R&DBUSS98_05 | 0.91 | 0.61 | 0.36 (0.19) | -0.63 (0.38) | 0.92 | 0.60 | 0.90 | 0.63 | 1.39 | 0.41 | 0.44 | 0.30 | 0.25 | 0.11 |
| R&DGOV_EDU98_05 | 0.57 | 0.22 | 0.58 (0.19) | 0.95 (0.38) | 0.57 | 0.22 | 0.56 | 0.22 | 0.70 | 0.19 | 0.42 | 0.13 | 0.39 | 0.12 |
| GDPPS97_04 | 97.80 | 35.25 | 0.14 (0.19) | 0.48 (0.38) | 97.76 | 34.36 | 97.84 | 36.68 | 125.89 | 18.68 | 82.28 | 9.68 | 47.98 | 7.32 |
| GROWTHGDP97_04 | 3.47 | 2.29 | 0.86 (0.19) | 1.74 (0.38) | 4.01 | 2.14 | 2.74 | 2.31 | 3.09 | 2.18 | 3.21 | 1.73 | 4.77 | 2.69 |
| LPRH99_05 | 83.61 | 29.80 | -0.13 (0.19) | -1.09 (0.38) | 82.99 | 29.77 | 84.46 | 30.03 | 107.94 | 13.80 | 66.58 | 13.76 | 43.75 | 7.74 |
| Valid N (listwise) | 163 | 163 | 163 | 163 | 94 | 94 | 69 | 69 | 84 | 84 | 36 | 36 | 37 | 37 |

R&DBUSS-GOVEDU: R&D expenditure Business enterprises minus R&D expenditure Government and for Education 1998-2005
R&DBUSS: R&D expenditure Business enterprises 1999-2005
R&DGOVEDU: R&D expenditure Government and for Education 1998 2005
GDPPS: GDP per Capita in PPS EU27=100 (1997-2004).

GROWTHGDP: Growth rate of GDP volume (1997-2004)
LPRH: Labour productivity per hour worked 1999 2005

Tab. 3A – indicators per countries

Source: Eurostat (2007)

| <i>Countries</i> | <i>Arithmetic mean</i> | | | | | |
|-----------------------------|------------------------------|------------------------------------|--|---------------------------------------|-----------------------------|-----------------------------------|
| | <i>GDPPS</i> <i>97_04</i> | <i>R&DBUSS</i> <i>98_05</i> | <i>R&D</i> <i>GOV_EDU</i> <i>98_05</i> | <i>R&DBUSS</i> – <i>GOVEDU</i> | <i>LPRH</i> <i>99_05</i> | <i>GROWTH_GDP</i> <i>97_04</i> |
| Austria | 130.9 | 1.41 | 0.69 | 0.72 | 99.5 | 2.2 |
| Belgium | 124.6 | 1.36 | 0.54 | 0.82 | 127.9 | 2.3 |
| Cyprus | 88.9 | 0.06 | 0.21 | -0.15 | 68.2 | 3.6 |
| Czech Republic | 71.8 | 0.76 | 0.46 | 0.30 | 48.4 | 2.0 |
| Denmark | 129.6 | 1.59 | 0.75 | 0.85 | 102.7 | 1.9 |
| Estonia | 47.3 | 0.24 | 0.49 | -0.25 | 39.3 | 7.2 |
| EU (15 countries) | 114.7 | 1.23 | 0.66 | 0.57 | 100.0 | 2.3 |
| EU (25 countries) | 104.7 | 1.19 | 0.65 | 0.54 | 91.0 | 2.5 |
| EU (27 countries) | 100.0 | 1.19 | 0.65 | 0.54 | - | 2.4 |
| Euro area (12 countries) | 113.6 | 1.18 | 0.66 | 0.51 | 102.6 | 2.2 |
| Euro area (13 countries) | 113.3 | 1.18 | 0.66 | 0.51 | 102.3 | 2.2 |
| Finland | 115.1 | 2.30 | 0.97 | 1.33 | 95.4 | 3.7 |
| France | 114.9 | 1.36 | 0.78 | 0.58 | 117.3 | 2.4 |
| Germany | 119.5 | 1.71 | 0.75 | 0.96 | 109.7 | 1.4 |
| Greece | 79.1 | 0.19 | 0.43 | -0.24 | 68.6 | 4.2 |
| Hungary | 57.9 | 0.34 | 0.47 | -0.13 | 50.6 | 4.6 |
| Iceland | 133.6 | 1.41 | 1.20 | 0.21 | 84.6 | 4.2 |
| Ireland | 131.1 | 0.81 | 0.37 | 0.45 | 115.0 | 7.6 |
| Italy | 115.6 | 0.53 | 0.55 | -0.02 | 96.0 | 1.5 |
| Japan | 117.0 | 2.26 | 0.74 | 1.52 | - | 0.9 |
| Latvia | 39.1 | 0.15 | 0.28 | -0.13 | 32.2 | 6.7 |
| Lithuania | 42.9 | 0.12 | 0.53 | -0.42 | 39.4 | 6.2 |
| Luxembourg | 236.7 | 1.45 | 0.17 | 1.28 | 154.3 | 5.1 |
| Malta | 80.0 | 0.26 | 0.19 | 0.07 | 76.1 | 0.2 |
| The Netherlands | 131.5 | 1.04 | 0.71 | 0.33 | 117.8 | 2.7 |
| Norway | 154.6 | 0.92 | 0.71 | 0.22 | 141.6 | 2.7 |
| Poland | 48.6 | 0.20 | 0.40 | -0.20 | 43.7 | 4.1 |
| Portugal | 77.2 | 0.23 | 0.44 | -0.21 | 58.7 | 2.6 |
| Romania | 29.0 | 0.26 | 0.14 | 0.13 | - | 4.2 |
| Slovakia | 53.2 | 0.37 | 0.24 | 0.13 | 52.3 | 3.4 |
| Slovenia | 78.9 | 0.85 | 0.55 | 0.30 | 64.0 | 3.9 |
| Spain | 98.2 | 0.52 | 0.45 | 0.08 | 89.4 | 3.9 |
| Sweden | 121.7 | 2.92 | 0.93 | 1.99 | 101.2 | 3.0 |
| Switzerland | 143.1 | 2.03 | 0.66 | 1.37 | 101.0 | 1.7 |
| The United Kingdom | 118.2 | 1.18 | 0.59 | 0.59 | 88.8 | 3.0 |
| The United States | 156.8 | 1.93 | 0.64 | 1.29 | 113.4 | 3.2 |