A 3 % R&D effort in Europe in 2010: an analysis of the consequences, using the Nemesis model

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Summary of the study

The Nemesis European macro-econometric model is used to determine the various economic mechanisms involved in the effects of innovations in competitiveness, employment (total and in research), growth and public authority budgets. It is particularly useful in studying the 3% of GDP objective for research in Europe in that, unlike most of the other models that are applied, technical progress is endogenous[7]*. In addition, it analyses a large number of sectors (thirty activity sectors) in the fifteen European countries, and it is this level of detail that is vital in judging the effects of R&D, as the research effort is spread very unevenly between the different sectors.*

A "3% scenario"[8]*, which keeps to the specifically European Barcelona objectives, has been constructed with the aim of analysing the repercussions of the objective on the European economy. It is compared to a "trend-based scenario"*[9]*, which is calculated by extending the "pre-Barcelona" trend*[10]*, this being used as a benchmark for changes in the variables and indicators studied for Europe and its partners. The main assumptions used for this 3% scenario*[11] *are based on:*

- *The link between the stock of knowledge and economic performance*[12]*;*
- *The portion of added-value gains distributed to employees*[13]*;*
- *Compliance with the Barcelona objectives in the "public-private" spread of sources of financing;*
- *The places in which R&D is carried out;*
- *The long-term convergence of Member States on the intensity of R&D.*

The Barcelona objectives: short and long-term macro-economic consequences

The period between now and 2010 is essentially a period of efforts to invest in R&D linked to achieving the Barcelona objectives; these include in particular a heavy increase in the number of jobs in R&D activities (1.6 million). However, certain macro-economic effects are already perceptible in 2010, though the most noticeable benefits of these efforts can be seen after 2010.

<u>Up to 2010, compliance with the Barcelona objectives</u>: R&D effort reaches its peak

Bearing in mind the time taken for R&D to bear fruit [(14)]*, the European economy over this period is essentially "boosted" by increased expenditure on R&D; in 2010 the extra GDP* [(15)]

[7] The stock of knowledge in the economy is fed by R&D expenditure in each sector (which is interdependent), and gives rise to innovations that improve the economic performance of countries in the Union

[8] Known in the report as "central scenario", due to the fact that certain variants in the scenario were calculated by changing the values of one of the assumption parameters; they are particularly useful in assessing the sensitivity of the results to these parameters

[9] Known in the report as "central total"

[10] The data subsequently shown should all be interpreted as being the difference between the results obtained by the central scenario and the trend-based total; see in particular graph 6 (page 24) and table 17 (Appendix 3, page 53)

[11] The variants in this scenario, which are presented in the report, are constructed by modifying the various assumption parameters. In addition, some add in the existence of public authority orders.

[12] Flexibility of 0.075 in 2002 to 0.124 in 2030

[13] Here, an additional third of the increase in actual salaries due to tensions on the labour market

[14] 3 years for private R&D, 5 years for public R&D

nevertheless reaches 1.7 % (0.24 % per year) against extra expenditure on R&D of only 1.1 % of GDP:

- *the time taken for R&D to bear fruit is such that productivity increases only a little: global productivity of factors is up by more than 0.8 % in 2010;*
- *the extra increase in GDP leads to a 1.4% increase in employment in 2010 and a 3% increase in real income. But, up to 2008, extra employment is higher than extra GDP), which is explained by the high employment content of R&D expenditure;*
- *there is an increase in all internal demand headings. In particular, increased consumption (2.4 % in 2010), plays a predominant role due to the increase in employment and real income. Total investment is up by 1.8 % in 2010;*
- *imports are up by 1.7 % and exports are down by 0.2 % in 2010*[16]*. The external deficit vis-à-vis non-European countries is thus increased during this period. However, the deficit starts to decrease from 2008.*

The growth phase due to innovation:

From 2010, the effects of R&D can be clearly seen:

- *growth is now led by increased demand due to lower costs, and therefore prices (global productivity gains of factors of 0.8 % in 2010 to 1.92 % in 2015, 3.11 % in 2020 and 5 % in 2030) and to the quality effect (improved product quality of 2.1 % in 2010 to 4.96 % in 2015, 7.5 % in 2020 and 11.1 % in 2030);*
- *GDP is up by 4.2 % in 2015, 7.0 % in 2020 and 12.1 % in 2030, equivalent to a growth surplus in volume terms of nearly 0.5 % per year*[17]*;*
- *This extra demand mainly affects two headings, consumption (5.7 % difference in 2015, 9.1 % in 2020 and 15.5 % in 2030), and external balance: exports (difference increases sharply from 2011, from 2.6 % in 2015 and 6.9 % in 2020 to 13.7 % in 2030) and imports (decrease from 2018, an outstanding performance if we bear in mind the strong growth that increases demand, with an increase of 0.8 % in 2015, followed by a drop of 1.2 % in 2020 and 3.2 % in 2030), due to increased competitiveness vis-à-vis countries outside the European Union;*
- *On the other hand, extra investment by companies is lower due to the overall gain in productivity of factors. It is only 2.1% in 2015, 3% in 2020 and 5.9 % in 2030;*
- *Similarly, the difference in employment is only 2.9 % in 2015, 3.9 % in 2020 and 4.9 % in 2030*[18] *(3.4 % excluding R&D): these are significant percentages, but much lower than those of GDP, as the gain in productivity of work is high – up to 8.1 % in 2030 –. Europe thus creates 3.1 million extra jobs between now and 2015, 5 million between now and 2020 and 10 million between now and 2030, including 2 million, 2.4 million and 3.1 million respectively linked to research*[19]*. Certain sectors even lose a few jobs despite fairly sustained growth. These results are consistent with the sustained growth of a Europe affected by demographic ageing;*

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[15] difference in relation to the trend-based scenario.

[16] The boost to demand, combined with price rises due to the repercussion on prices of the extra cost of R&D, affects the export trade.

[17] This growth is equivalent to the volume of added value and does not include the extra quality, and therefore well-being, induced by innovation policy. According to the model's variants, the extra growth in European GDP should be between 10.9 % and 15.8 % in 2030. Depending on the initial level of R&D in countries, it will be situated annually between 0.2 %, as in Sweden, and 2 %, as in Greece.

[18] Approx. 1.1 million per year on average. The repercussions of the R&D policy on job creation in each country are increasingly significant, in terms of the proportion of the active population in the country, according to the extra amount of research carried out. Thus, the share of new jobs in Greece compared to the total number of new jobs in Europe is 8 %, while it is only 0.6% in Sweden and 10% in France.

[19] I.e. nearly 400,000 per year on average.

- *Finally, of course, the method of financing R&D efforts does not increase the load on the budget and therefore the government deficit. Its effects are globally positive over the long term (improvement of 2.33 points in GDP in 2030, i.e. an average of 0.085 points per year).*

With regard to the efforts and results of Member States, those countries that initially had a less intensive R&D programme (mainly in Southern Europe) will, in the medium and long term, make the greatest gains in productivity and therefore competitiveness according to the amount of "catching-up" they have to do with their R&D.

The transformation of the manufacturing structure

The policy of 3% of GDP for research in Europe will therefore considerably change the contribution to growth of the various sectors of production that go to make up the European economy. From the point of view of effects and results, four groups of sectors may be picked out: the R&D-intensive sectors, the intermediate goods sectors, the investment goods sectors (not included elsewhere) and the consumer goods sectors:

- *the R&D-intensive sectors[20]: all these sectors have a high production growth rate, with the gain in 2030 varying between 14.6 % for transport equipment and 22.3 % for office machines. Employment increases much less than production due to strong productivity gains engendered by R&D. In these sectors we also see R&D jobs gradually substituting those involved in production, higher product quality and increased market share;*
- *the intermediate goods sectors[21]: progress of factors in global productivity will naturally bring down demand for these products. In addition, as their R&D content is relatively small, improvements in quality and improved manufacturing processes are not likely to boost demand to any great extent. Employment is therefore slightly down;*
- *the "other investment goods" sectors[22]: As for the previous sectors, the R&D content is low, and the limited gains in productivity and quality in these sectors do not allow them to increase demand as much as the average for other sectors in a context where, in addition, their clients are achieving significant productivity gains and reducing their levels of investment;*
- *the consumer goods and services sectors [23]: These sectors are favoured by their increased R&D effort, by the increase in actual salaries and, more generally, the increasing buying power of households, and by the "quality" effect. Final consumption in households is thus a major driving force behind the growth taking place in Europe, and a number of consumer goods sectors see their production going up by over 15 %, with most of them exceeding 10 %. There is also a strong increase in employment in all these consumer goods and individual services sectors, thus creating a virtuous circle, with growth feeding on itself and bringing with it growth in every other sector of the economy.*

The sensitivity of results to the model's parameter values

"Variants" around the 3% scenario highlight the sensitivity of the results to the values chosen as the quantitative parameters for the assumptions. In particular, the report underlines:

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[20] Chemicals, office equipment, electrical goods and transport equipment, and commercial research subcontracting services.

[21] Ferrous and non-ferrous metals, non-metallic mineral products, metal, rubber and plastic products. The chemical industry, which includes pharmacy, is considered to be one of the R&D-intensive sectors.

[22] Machinery for agriculture and manufacturing, other industries and construction.

[23] Food, drinks and tobacco, textiles, clothes and shoes, paper and printing products, accommodation and catering, and transport services.

- *the differences in the effects of investment depending on its source – private or public –. Public financing of all the extra investment in R&D appears to have better long-term effects in terms of growth (8.8 % compared to 7 % in 2020 and 15.2 % compared to 12.1 % in 2030) and employment (6.9 million and 13.9 million jobs created instead of 5 million and 10 million between now and 2020 and 2030), but, on the other hand, this type of financing may have negative consequences on the financial balance in 2010 (– 0.81 % compared to + 0.13 %); however, by 2030, increased growth allows the financial balance to increase by 1.97 % of GDP (compared to 2.33 %);*
- *the effects of the distribution of increased growth on salaries (sharing of added value). The model's conclusions show that, if employees appropriate all the productivity gains engendered by adhering to the Barcelona objectives, this would be harmful to long-term employment as it would limit potential for investment, and therefore innovation, but would have little influence on production. But this result needs to be kept in perspective by noting on the other hand that growth is likely to be led by exports, and not so much by increased internal consumption*[24]*;*
- *the major role that may be played by public-sector orders. In one of the variants of the model, public-sector orders are placed with R&D-intensive sectors (chemicals, office, electrical and transport equipment) to the value of 2.5 % of GDP. They lead to increased R&D activity of a third of the effort required to achieve the Barcelona objectives*[25]*. They engender an initial increase in public and external deficits, but also strong growth (GDP up by 2.5 % in 2010, 5.7 % in 2015, 9.2 % in 2020 and 15.8 % in 2030) accompanied by the creation of large numbers of jobs (gain of 3.5 million in 2010, 5.9 million in 2015, 9.1 million in 2020 and 17.1 million in 2030), due to high multipliers. In addition to the boost given by increased public expenditure, the economy benefits from the concentration of extra R&D effort in high technology sectors, which take advantage of higher R&D productivity and are major purveyors of knowledge spillovers and surplus spillovers. In addition, the slightest growth in productivity in highly labour-intensive sectors, which is the corollary to this concentration on sectors that are already very R&D-intensive, leads to strong growth in employment.*

Lastly, it is important to note that the results concerning employment in research are little different from the chosen assumptions. Employment needs linked to research are shown to be a major constraint, and this should be reflected as a matter of urgency in R&D policy and in education, training and employment policies.

Limitations, contributions and lessons learned from the results of the model

The comparison of the "3% scenario" results and its variants with those of a "trend-based scenario" is well suited to the question being asked, as it clearly highlights the major repercussions of policies linked to the 3 %, independently of any other political action within the European Union and of any specific reaction from non-European countries, which is expressed in particular by the maintenance of fixed exchange rates. We must realise, however, that to consider other policies as being exogenous is also to limit the analysis. In particular, it has been assumed that increasing staff needs for research could be satisfied by the availability of competent staff. It has also been assumed that the significant efforts required by the objectives could be made by all countries, especially the less rich, such as Greece, for whom the efforts are higher than the average. Lastly, the model still focuses on a

[24] Passing on all productivity gains linked to the "3% policy" to businesses does not mean that salaries do not go up. There are other, endogenous mechanisms that link salaries and the level of economic activity.

[25] The remaining two-thirds are achieved as in the benchmark variant

European Union with fifteen countries. However, in the knowledge that no model can include all the complex mechanisms governing the functioning of a real economy, these results should be interpreted with the customary precautions.

Having established the framework, all the results presented in the report create an important "tool" for the organisations concerned by the repercussions of the "3% policy". They offer a great deal of useful information, in particular:

- *GDP increases by approx. 0.25 % per year before 2010 (0.5 % per year afterwards);*
- *The number of jobs linked to research increases sharply (over 1.6 million between now and 2010, a very stable figure vis-à-vis the assumptions, with, thereafter, an extra annual need for nearly 80,000 people. The difference reaches over 3.1 million in 2030);*
- *in 2015, the total increase in jobs is between 2 and 6 million (3.1 in the 3% scenario) and in 2030 between 5 and 18 million (10 million in the 3% scenario);*
- *budget balances deteriorate when the 3% policy is first introduced, but are broadly improved thereafter;*
- *all the European sectors increase their competitiveness vis-à-vis the rest of the world, even though the two less R&D-intensive groups of sectors see their contribution to European growth reduced;*
- *those European countries that are "catching up" in terms of their R&D effort will see their relative competitiveness improve at a European level;*
- *within the Union, the competitiveness of the most R&D-intensive countries improves initially, as they have to make less extra research effort than most of their European partners; however, during the second period, the least R&D-intensive countries in 2002 (mostly from Southern Europe) catch up, which leads to gains in productivity and product quality that are clearly superior to those for Germany, France, Belgium and the countries of Northern Europe, whose competitiveness after 2010 relative to the former countries is reduced.*

In the years to come, efforts to achieve the Barcelona objectives should lead to a major transformation of the economic and social landscape in Europe and involve a wide variety of policies (research, education, employment, enterprise, economy and finance…). Discussions now seem to be required in order to gain a better analysis of how these policies will dovetail – at a national and community level – in the short and medium term, and of the consequences of the ambitions set out in the Barcelona objectives.

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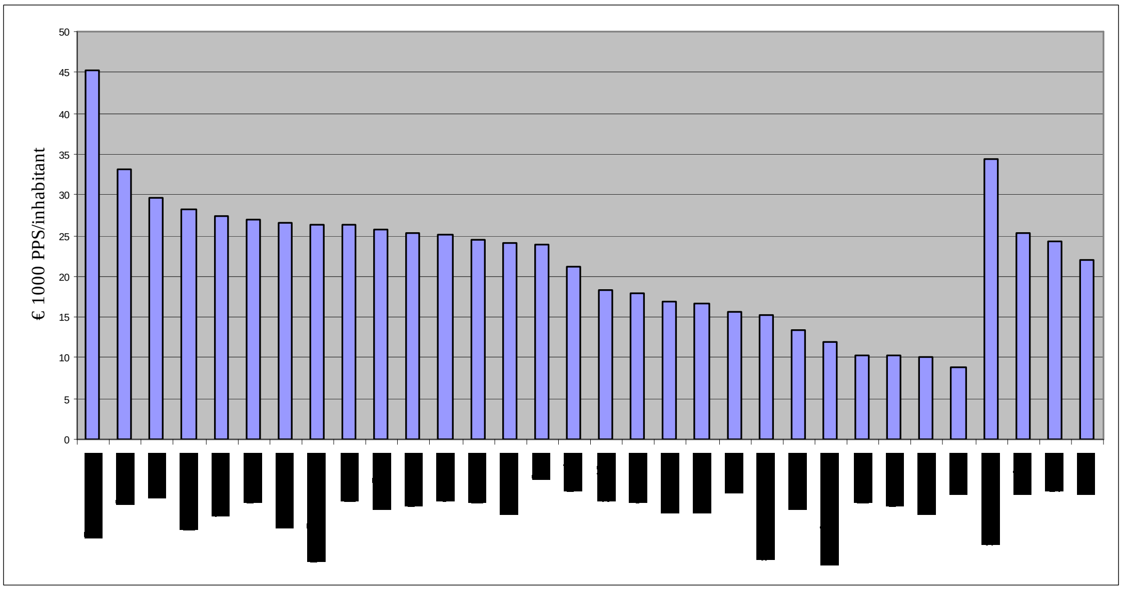
Introduction

With an annual growth in GDP of 3.6 % in the third quarter of 2003, the United States is enjoying an economic upturn that further widens the gap with countries in the European Union, whose growth rate is evaluated at only 0.6 %[26]. The United States is one of the few countries in the OECD to have seen its growth in GDP per inhabitant accelerate (graph 1). In 2003 it had the highest GDP per inhabitant, followed by Norway, Ireland and Switzerland (with a GDP per inhabitant 8 % to 18 % lower than the United States). GDP per inhabitant in the European Union is around 30 % below that of the United States. A number of explanations may be put forward, such as the increased value of the euro and the increase in public expenditure in the United States in 2003; however, one of the key reasons for economic performance is to do with commitment to innovation.

Graph 1. GDP per inhabitant in Europe, the United States and Japan from the perspective of the PPS, 2003



Source: DG Economic and financial affairs, European Commission

In 2001, the United States spent[27] 307 billion euros on research and development (R&D), the European Union 176 billion and Japan 143. R&D expenditure represented 2.8 % of GDP in the United States in 2002, 1.99 % of GDP in Europe in 2001 and 2.98 % of GDP in Japan in 2000.[28] The difference between the European Union, the United States and Japan is the result of ten years of increasing divergence in R&D expenditure in the two zones[29]: After a period in which R&D intensity fell up to 1994, the United States and Japan experienced a period of strong increase during which the annual rate of growth in R&D intensity was 1.8 % in Japan and 1.6 % in the United States. Over the same period, R&D intensity in Europe remained relatively stable, with slight growth between 1995 and 2000 (+0.4 % per year). Faced with this situation, heads of state and government met at the European Council in Lisbon in March 2000 to set the European Union the objective of becoming, between now and 2010, "the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth accompanied by an improvement in the quantity and quality of employment and greater social cohesion." To achieve this objective, they decided at the European Council in Barcelona, in March 2002, to increase investment in R&D to 3 % of GDP in 2010.

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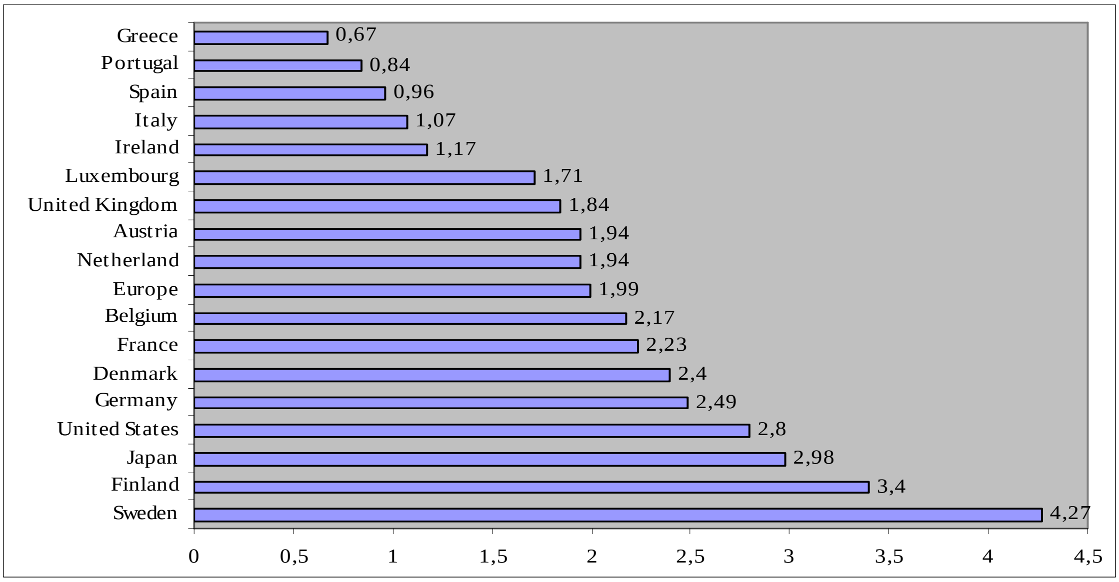
[26] Eurostat forecasts (press communiqué of 15 January 2004).
[27] In purchasing power parity.
[28] The relationship between R&D expenditure and GDP defines the intensity of R&D.
[29] For every 100 euros spent in the United States, the Europeans spent 72 euros in 1991 and only 62 in 2000.

The objective of 3 % of GDP dedicated to R&D is an ambitious one for Europe, where the research effort made by its member states is very unequal. Graph 2 shows the great variety of R&D intensity: while Greece dedicates only 0.67 % of its GDP to R&D, Sweden dedicates 4.27 % of its GDP. However, these differences in intensity should be analysed in the light of the weight of each country in terms of total R&D expenditure in the Union. Germany, France, the United Kingdom and Italy represent nearly three-quarters of Union expenditure. Yet their expenditure rose by only 9.7 % between 1995 and 2000, while that of the European Union went up by 14.1 %. The northern countries (Denmark, Finland and Sweden) spend one tenth of the Union's R&D. They increased their R&D effort by 33 % over the same period. Lastly, Greece, Ireland and Portugal are responsible for only 1.6 % of European expenditure. They saw the greatest increase, of 45.7 %, in R&D expenditure between 1995 and 2000. Despite an apparent convergence within the European Union, increased R&D expenditure in the least R&D-intensive countries does not allow them to reach the 3 % threshold that has already been exceeded in Sweden and Finland. If R&D intensity continues to grow in line with recent trends, it is not likely to exceed 2.3 % in 2010. The most pessimistic scenario forecasts an intensity of only 1.8 % in 2010. The gap will continue to widen with the United States, whose intensity should reach 2.6 % to 3.1 %, and Japan, whose intensity is likely to be 3.2 % to 3.8 % (European Commission, 2003a).

Graph 2. R&D intensity for the last available year[1]



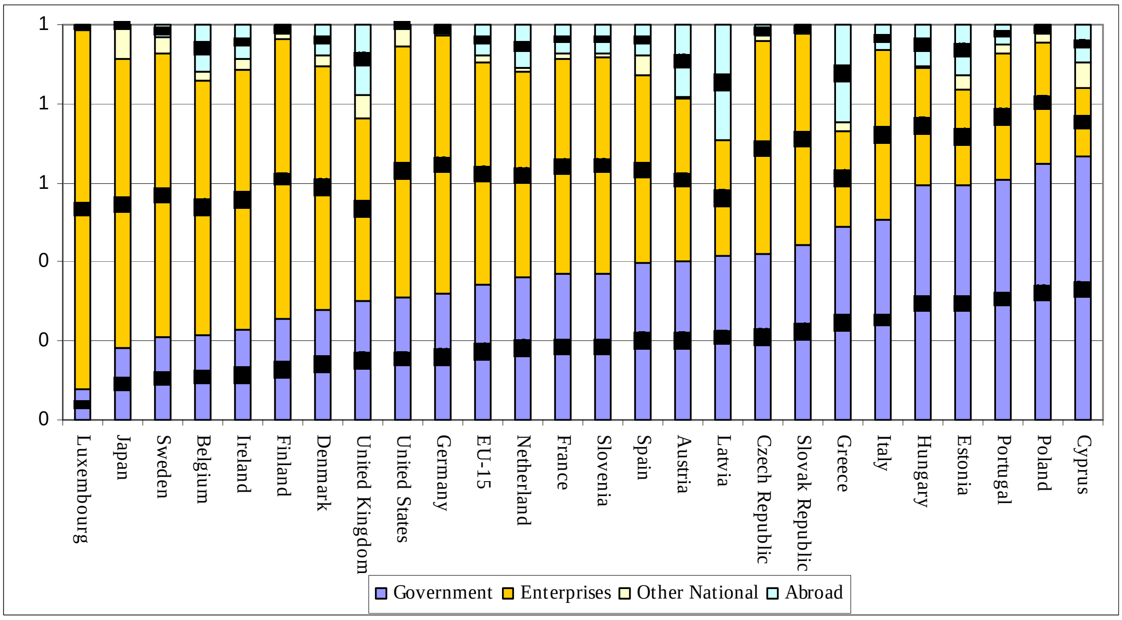
[1]2002 for Austria, the United States, Finland, France and the United Kingdom; 2001 for Germany, Belgium, Denmark, Spain, Ireland, Portugal and Sweden; 2000 for Greece, Italy, Luxembourg, the Netherlands and Japan.

Source: Eurostat

The European Union's late start compared with the United States is mainly due to the dynamism of American companies in the financing of R&D (graph 3).[30] This is why, at the Barcelona Council, it was decided to raise the share of R&D financed by the private sector from 56 % to two-thirds of total investment in R&D in 2010, i.e. 2 % of GDP. This objective is also an ambitious one, as the gap between the United States and the European Union has grown ever wider since 1995. Although the share of R&D financed by the private sector is tending to grow in the United States and in Europe, it has increased much more rapidly in the United States (+8.4 % per year on average between 1995 and 1999) than in the European Union (+4.9 % per year).

[30] American companies also play a much greater part in carrying out R&D than European companies: they finance 66 billion and carry out 71 billion euros worth of R&D more than European companies.

Graph 3. Sources of R&D financing
(as a % of total R&D)



Source: DG Research, European Commission. Data: Eurostat, OECD. Years: 2001, except IT: 1996; EL: 1999; CY, EE, IE, LU, LV: 2000; DE, CZ, HU, SK: 2002; AT, US: 2003.

The Barcelona objective nevertheless requires a sustained effort from government in the financing of R&D. The share of R&D that it finances has fallen steadily since 1995 in the European Union, to reach 0.66 % of GDP in 2000, and in the United States, where it is 0.76 % of GDP. On the other hand, it has increased in Japan as a result of its first plan for science and technology, the aim of which is to encourage R&D. In 2000, the Japanese government allocated 0.58 % of GDP to R&D. According to European Commission projections (2003a), if the reduction in the government share in the financing of R&D continues to follow the current trend, it will be financing between 0.4 % and 0.5 % of GDP in 2010. European governments must therefore increase the volume of R&D that they are financing if they wish to achieve the objective that has been set. This financing is part of the dynamic for research in companies, and therefore part of the increased R&D effort itself.

The desire for increased research in Europe is dictated by the objectives for competitiveness, sustainable economic growth and improvements in employment announced in Lisbon. However, the effects of innovations on the productivity of factors, competitiveness, employment and growth are the result of complex phenomena. Growth theories and empirical research into innovation help to throw light on these. The Nemesis macro-econometric European model is used to focus even more closely on the various economic mechanisms and their interactions and to assess the consequences in terms of growth and employment, needs in terms of the number of researchers and government deficit. The Nemesis model is particularly well adapted to such a study in that, unlike most of the other models that are applied, technical progress is endogenous: the stock of knowledge in the economy is fed by R&D expenditure in each sector, which are themselves interdependent, and gives rise to innovations that improve the economic performance of countries in the Union. In addition, the analysis is carried out in detail sector by sector (thirty activity sectors) for the fifteen European countries: this level of detail is essential in assessing the effects of R&D. We will focus this report on the consequences of the R&D policy for certain representative countries in the European Union. Two countries very involved in European research (France and Belgium), a Northern country that is very R&D-intensive (Sweden) and one of the least R&D-intensive countries (Greece) for whom the Barcelona objective is the most ambitious. We will carry out the analysis by systematically relating our results to those achieved on average in the European Union.

However, the results of the simulations presented should not be considered to be final and beyond discussion; firstly, because we do not yet have reliable information on measurements and the timings for implementing policies, even though the objectives may seem clear; secondly, because the mechanisms affecting research and development, and, more particularly, the chain that leads to the decision to increase R&D until economic performance improves, remain partly obscure despite a great deal of theoretical and applied research over recent years. This double line of uncertainty means that we must be very careful in our assessment of the results. One way of controlling reality or improving the measurement of the effects of policies that have been introduced is to increase the number of variant-based exercises (sensitivity tests on the essential mechanisms in the model, and simulations carried out under various conditions in which economic policies are implemented).

The first part of the report throws light on the economic mechanisms that make innovation one of the driving forces of economic activity. The second part is given over to incorporating endogenous technical progress into theoretical and applied models, including Nemesis. Part three deals with the results of simulations of the 3 % R&D intensity policy. We will analyse in detail the results of a benchmark scenario whose functioning and implementation characteristics are “median”. This central scenario is then set out in a range of alternative scenarios used to give a better understanding of the consequences of a more intense research effort that can be envisaged for countries in the European Union.

1. The economic mechanisms of innovation

Economic growth in the OECD countries is very largely explained by the dynamism of innovation. Innovation improves the productivity of factors of production and changes the price competitiveness and structural competitiveness of economies, thus favouring increased GDP. International distribution creates positive spillover through productivity gains in a broader range of sectors than those in which the innovators are operating. The development of new information and communication technologies (ICT), sometimes called the “third industrial revolution”, thus plays an increasingly important part in explaining the differences in growth between OECD countries. However, innovation’s effect on productivity leads to fears of negative impacts on employment. In this part, we discuss all these phenomena, which help us to understand how innovation affects a country’s economic performance.

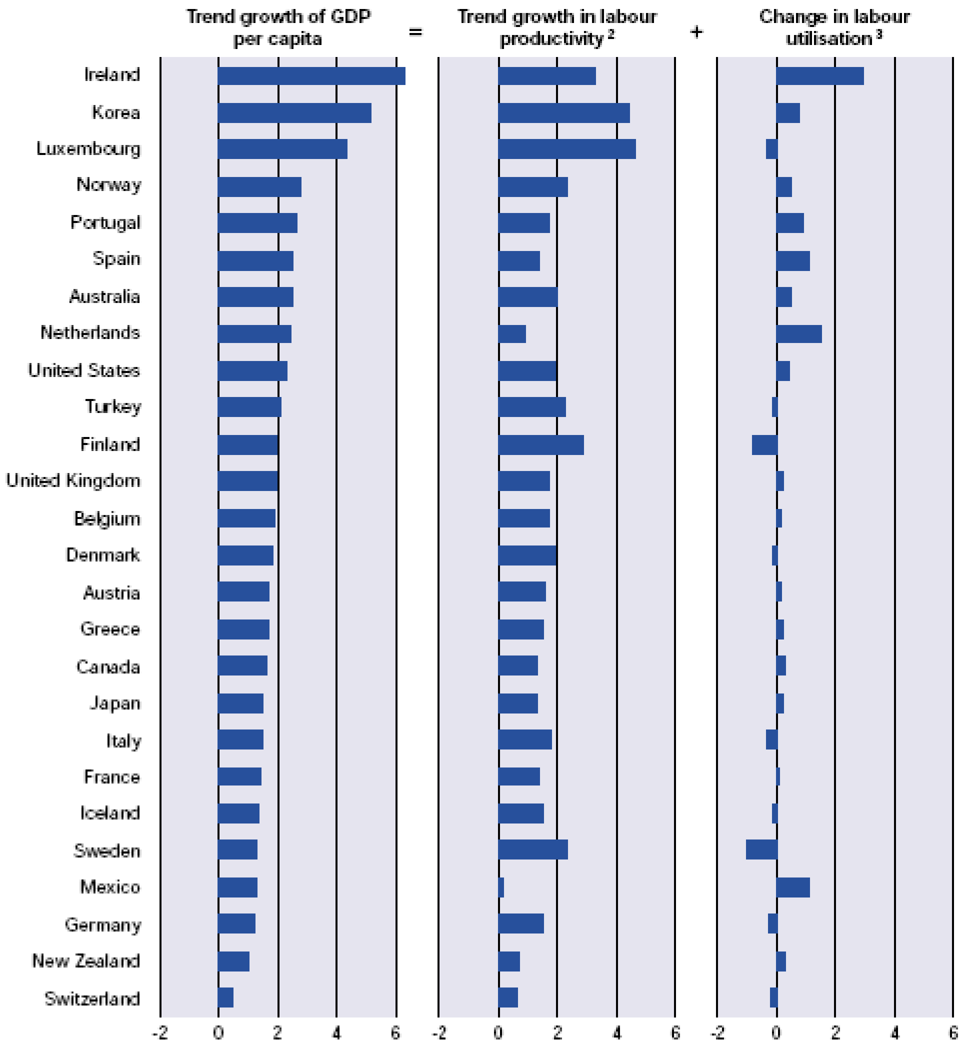
1.1. Increased productivity

Innovation helps to increase the productivity of capital and/or labour. It can sometimes make the relationship between capital and labour more effective. More generally, innovation improves the global productivity of factors. Changes in the global productivity of factors are closely related to changes in labour productivity, as the remuneration of labour in GDP is of the order of 70 %, while the relationship between GDP and capital remains relatively constant. It is therefore interesting to examine the size of the contribution of differences in the growth in labour productivity and the use of the labour force with differences in the growth of GDP[31] between the OECD countries in the 1990’s (graph 4).

[31] GDP is the factor of the productivity of labour and of the labour force. The rate of growth of GDP can thus be explained as the sum of the rate of growth of the productivity of labour and the productivity of the labour force.

Graph 4. Breakdown of trend-based growth of GDP per inhabitant

Variant in annual percentage, 1990-1999[1]



[1]1991-1999 for Germany, 1990-1998 for Korea and Portugal
[2]Trend-based growth of GDP per person employed.
[3]Trend-based growth in the use of the labour force, measured by the ratio between the number of people in a job and the total population.

Source: OECD (2001)

After a long catch-up process, hourly labour productivity is now very much the same in Europe and the United States (Gordon, 2002). However, while the use of the labour force has improved in the United States, some European countries have experienced only a slight growth in employment. This explains why the rate of trend-based growth[32] was 2.1 % in the United States and 2 % in the European Union in the 1980's, then 2.3 % in the United States and only 1.8 % in the European Union in the 1990's. The end of the decade was marked by accelerated growth in the United States (2.8 % between 1996 and 2000) and an upturn in Europe (2.2 % over the same period), mainly due to the dynamism of Luxembourg, Norway, Spain, the Netherlands and Greece.

[32] The trend-based growth rate is a growth rate corrected by trend-based fluctuations. It is better adapted than the simple GDP growth rate per inhabitant for making an international comparison of economic performance.

Table 1. Annual growth rate (%) in the global productivity of factors *

	1980-1985	1985-1990	1990-1995	1995-2000
Finland	2.47	2.33	2.74	3.58
Canada	0.49	0.77	1.00	1.61
Austria	0.68	0.46	1.19	1.47
United States	0.82	1.03	0.96	1.31
France	2.02	1.71	0.93	1.09
United Kingdom	-	1.01	0.66	0.96
Germany	1.16	1.82	1.05	0.84
Japan	1.92	2.38	1.24	0.74

* The measurement for the average productivity of factors is the broadest measurement supplied by the OECD as it includes the effects of progress on human assets and technical progress incorporated and not incorporated in physical assets.

Source: OECD (2003)

Since 1973, changes in productivity have been paradoxical: while R&D increased sharply for twenty years, the productivity growth rate stagnated around 1 % in the industrialised countries, having reached 3 % in previous years. This productivity paradox made Solow say that he saw computers everywhere, except in the productivity statistics. The 1990’s were nevertheless marked by a renewed growth in productivity, which led to questions as to whether the paradox had come to an end. To answer the question, we need to examine the reasons put forward with regard to Solow’s paradox:

— Firstly, a statistical reason, linked to the difficulty in measuring the global productivity of factors[33];
— Secondly, a structural reason resulting from the increase in product innovation, aimed at differentiating products, to the detriment of technological innovation, which directly influences productivity (Boyer, Didier, 1998). However, this argument needs to be placed in context: the increase in the quality of products leads to an increase in the volume of efficiency of production[34] and, therefore, to increased productivity. This effect is unfortunately omitted from national accounting statistics.
— Joly (1993) implicates the completion of the other industrial nations’ efforts to catch up with the United States, the reduction in the accumulation of capital and the slowdown in technical progress.
— Griliches (1992) considers that it takes time for the faster pace of technological innovation in the 1970’s and 1980’s to come through into statistics for the global productivity of factors. The latter argument tends to be confirmed by the growth in productivity in the second half of the 1990’s in a number of OECD countries, and in the United States in particular (OECD, 2001).
— Askenazy (2000) uses company data to demonstrate that the Solow paradox could be explained by a lack of reorganisation of work in some companies, which, despite the rapid rise in the use of information technology, were seeing their productivity falling. Companies that integrated information technology and reorganised work are thought to have made productivity gains. The Solow paradox is thus thought to have arisen simply from an agglomeration of the results of these winning and losing companies. With 80 % of American companies taking on information technology and reorganising work at the end of the 1990’s, the United States have recently “emerged” from the Solow paradox.

Econometric studies carried out in firms confirm the influence of R&D expenditure on the growth of the global productivity of factors (Table 2). The inventory of these studies by Mairesse and Sassenou (1991) enables them to conclude that there is an elasticity between productivity and R&D of 0.1 to 0.3 where the analysis is based on individual data. This

[33] The various productivity measurements are analysed by Schreyer and Pilat (2001).
[34] By volume of efficiency we mean the volume of production increased by the rate of growth in product quality. If production in volume terms remains at 100 euros (at a constant price) before and after the innovation but the quality increases by 10% thanks to the innovation, then the volume of efficiency is 110 euros after innovation. Productivity, the ratio between the volume of efficiency and the production factor quantity used, thus increases following the product innovation.

elasticity is higher in high technology sectors. Chronological series studies show much lower elasticity levels of between 0.02 and 0.05 for French companies, and between 0.08 and 0.12 for American companies. This low level is doubtless due to the time needed for an innovation to have a real impact on productivity. It is also due to the fact that an innovating company wins market share from its competitors within the same activity sector. Studies that differentiate elasticity by activity sector show that R&D productivity increases with the degree of technological advancement in the sector: it is strongest in R&D-intensive sectors and therefore in R&D-intensive countries. At a macro-economic level, a number of OECD studies, in particular that of Guellec and van Pottelsberg (2001) which looks at sixteen OECD countries, also highlight the positive influence of R&D on the global productivity of factors.

Table 2. The impact of R&D on the global productivity of factors

Authors	Sample	Elasticity of R&D
Cross section		
Minassian (1969)	17 chemical companies	0.26
Griliches (1980)	883 American companies	0.07
Schankerman (1983)	110 chemical and oil companies	0.16
Griliches-Mairesse (1984)	77 American companies	0.18
Cunéo-Mairesse (1984)	98 French companies	0.21
Mairesse-Cunéo (1985)	296 French companies	0.16
Griliches (1986)	491 American companies	0.11
Jaffe (1986)	432 American companies	0.20
Sassenou (1988)	112 Japanese companies	0.16
Chronological series		
Minassian (1969)	17 chemical companies	0.08
Griliches (1980)	883 American companies	0.08
Griliches-Mairesse (1984)	343 American companies and 185 French companies	0.02
Griliches-Mairesse (1984)	133 American companies	0.09
Cunéo-Mairesse (1984)	182 French companies	0.05
Mairesse-Cunéo (1985)	390 French companies	0.02
Griliches (1986)	652 American companies	0.12
Jaffe (1986)	432 American companies	0.10
Sassenou (1988)	394 Japanese companies	0.04

Source:Mairesse and Sassenou (1991), used by Boyer and Didier (1998).

By increasing the global productivity of factors, innovation improves price competitiveness. Innovation in processes tends to reduce companies' unit production costs, which allows them revise prices downwards. Product innovation leads companies to offer better-quality products and more diverse ranges. These new products pull prices upwards, thereby damaging the economy's price competitiveness, due again to the partial inclusion of the quality effect in national accounting price indexes[35]. Product innovation and process innovation also tend to improve the structural, or price-exclusive competitiveness of an economy, and thus its ability to attract demand through factors other than price. Finally, we learn from empirical research that innovation works in favour of competitiveness. Magnier and Toujas-Bernate (1993), for example, highlight the positive impact of R&D expenditure on companies' export performance.

1.2. Changes to the nature of jobs

The only certainty that we have with regard to the impact of innovation on employment is that the nature of jobs will change with innovation. The answer is less clear concerning the vital issue of the creation or loss of jobs following on from innovation.

The nature of jobs changes in innovative companies. Improvements to the quality of products lead to more complex production processes and the need to review the organisation and even the company to guarantee product quality (making workers responsible, self-

[35] In the Nemesis model, the greatest satisfaction due to the increase in quality is taken into account through hedonistic prices that change like the value-for-money ratio of goods (if the price goes up by 10 % and the quality also goes up by 10 %, the hedonistic price does not vary). A product innovation then leads to a fall in the (hedonistic) price of the product, and not a rise.

inspection). A number of econometric studies show that an increase in product quality is accompanied by increased worker skills within the company[36] (Cardebat, 2003). Innovation may then give rise to a discrepancy between labour supply and demand.

At a macro-economic level, innovation leads to a fall in the number of jobs in innovative sectors (as in manufacturing industry) and to job creation in high growth sectors (such as services). At the same time, the average skill level in jobs tends to rise. For this reason, in addition to a certain flexibility in the labour market, changes in this market need to be supported by changes to the education system. This is particularly important as, in order to achieve the Barcelona objective, jobs linked to R&D need to increase. It is vital to have qualified employees, particularly ICT specialists, scientists and engineers to see innovative projects through to their conclusion. In the 1990's, "learned workers" such as researchers, engineers and ICT specialists represented nearly 30 % of net growth in employment in the OECD countries. These countries suffer, however, from a lack of qualified staff and therefore need to review their education systems (basic education, higher education and continuous training) to meet the growing demand from companies[37]. Certain countries, such as the United States, have solved the problem in the short term by using foreign labour (for example, in Silicon Valley, where a third of the labour force is made up of immigrants). China, India and Russia also suffer as a result of their scientists and engineers moving abroad. The relocation of certain production units abroad could also compensate in the short term for this lack of skilled labour. The European Union needs to increase the number of researchers by 500,000 between now and 2010 to achieve the Barcelona objective (Sheehan and Wyckoff, 2003). It is therefore vital to produce the means to train and recruit them.

By increasing productivity, does innovation lead to job losses? The answer seems to be negative if we look at changes in jobs over a long period: major increases in productivity at certain times, as during the "thirty glorious years" have been accompanied by more job creation than at other times in history. However, process innovation does generate job reductions in companies, if production remains unchanged. But job creation can sometimes occur when an innovative company increases its market share as a result of extra demand due to a reduction in the price of a product or a product innovation.

Econometric studies generally show that innovative companies have a higher level of employment than those that do not innovate, due to the rate of growth of their higher sales figures (see, for example, Crépon and Iung.1999). However, sector-based analyses confirm this positive impact of innovation on employment only in certain sectors with high technological intensity, such as the pharmaceuticals industry and office machinery (Boyer, Didier, 1998). The impact of innovation on demand and thus on production and employment still does not always compensate for the effect of increased productivity on the level of employment.

To answer the question about the impact of innovation on employment, a macro-econometric model like Nemesis seems particularly suitable, as it quantifies the direct and indirect effects of innovation on the level of employment. It thus provides an evaluation of the sector-based and global consequences on employment of increasing R&D expenditure, up to 3 % of GDP in 2010. These consequences depend on the assumptions chosen concerning the method of financing increased R&D activity (the share of private finance) and the sharing of productivity gains between employees (through an increase in actual salary) and companies (through an increase in profit).

[36] The strategy of horizontally differentiating products also leads to the recruitment of increasingly skilled workers to meet the need for considerable flexibility in the face of competition (in order to continually renew its product range, the company makes increasing use of information and digital technology, which make it more reactive to the competition), and to adapt to a new production approach that requires design, creation and marketing to be kept within the company and manufacturing to be relocated.

[37] At a meeting in April 2001, OECD Ministers of Education expressed the need to introduce a coherent lifelong learning strategy (OECD, 2001).

1.3. The new information and communication technologies: the driving force for growth over the last ten years

The new information and communication technologies (ICT)[38] cover a large number of innovations, such as microprocessors and other microelectronic components (whose performance continually improves), optical fibres, lasers, software, etc. In the second half of the 1990's they accelerated the increase in the global productivity of factors and considerable growth in GDP per inhabitant in the United States, Finland, Canada, Greece, Iceland and Sweden. The OECD (2003a, 2003b) identifies three transmission channels through which ICT affects growth rates: (1) faster productivity in the producer sector itself, and its increasing importance within the economy, (2) accumulation of capital and (3) its knock-on effects on the global productivity of factors.

(1) In 1999, the ICT sector represented nearly 13 % of the added value of companies in Finland and Ireland, 11 % in the United States, 9.8 % in France, 8.4 % in Japan and 7.1 % in Germany. The sector experience sharp growth in labour productivity between 1995 and 1999, especially in the United States where it increased by 79 % in the telecommunications equipment sector des and by 264 % in the computer equipment sector, while productivity across the whole of manufacturing industry rose by only 26 %.

(2) The ICT sector was the most dynamic in terms of investment over these years. Investment was favoured by a fall in prices of around 15 % per year[39] between 1970 and 1998. The share of investment in companies' ICT products in the GDP is much higher in the United States (4.5 % of American GDP in 1999) than in Europe (2.4 %). While this type of investment represents a third of GFCF in the United States and Finland, it is equal to only a sixth of GFCF in France, Japan and Germany. The difference between the United States and Europe is particularly marked in that European companies share of investment in the GDP is still much lower than that of American companies and the annual rate of increase in the volume of investment in the European Union was only 2.8 % between 1990 and 2000, compared to 8.1 % in the United States (Kergueris, 2002). In addition to the direct effect of the ICT sector on the increase in the stock of capital, the increased share of ICT in investment has led to improvements in the quality of the stock. The impact of this investment on GDP has been strengthened.

(3) ICT has led to the formation of networks between suppliers, and also between manufacturers and consumers, thanks to the Internet. It has encouraged companies to change, improve the organisation of work, reduce transaction costs and rationalise production. It has also stimulated innovation in the service industries. The trend-based rise in the global productivity of factors incorporates these various effects. It was particularly high in Finland (with an annual growth rate of 1 % between the 1980's and 1990), Australia, Ireland, Canada, Sweden, Denmark, Norway, the United States and New Zealand (+ 0.5 %). This growth was even more marked in the second half of the 1990's. On the other hand, Japan and most of the countries in Europe lost productivity. Germany experienced an annual fall of 0.4 % growth in the global productivity of factors between these two periods and France saw a reduction of 0.9 % (OECD, 2001).

Many econometric studies have sought to quantify the impact of the development of ICT on the growth of industrialised countries. Colecchia and Shreyer (2002) showed that, between 1995 and 1999, investment in ICT contributed a 0.9 percentage point to the annual growth of GDP in

[38] According to the OECD definition, the ICT sector includes part of the manufacturing industry (mainly the manufacture of computer and telecommunications hardware), services linked to the supply of these assets (sale and hire of office machinery and computer hardware) and intangible services (telecommunications, computer activities and radio and television services). France uses a very similar definition to that of the OECD, while the United States has a more far-reaching definition. International comparisons in this area should therefore be made with caution (Didier, Martinez, 2000).

[39] The change in prices is corrected by the quality effect, which tends to increase prices as ICT performance improves.

the United States. Australia and Finland experienced a similar contribution. Japan, Germany, France and Italy gained the least benefit from this type of investment. A comparison of research by Jorgenson et al. (2003) on the United States and Melka et al. (2002) on France allowed Debonneuil and Fontagné (2003) to show that ICT's contribution to the increase in added value was only as half as much in France as in the United States (Table 3): the acceleration in American growth in the second half of the 1990's was mainly due to an increased accumulation of capital, half of which came from investment in ICT, while France's lack of dynamism is explained by a lack of investment, under-use of labour and a lesser global productivity of factors.

The development of ICT in the United States and its impact on growth and productivity gains illustrates the links that can occur between innovation, productivity and growth, as long as the conditions of this virtuous circle (especially the reorganisation of work) are all combined. These links are at the heart of growth theories and, increasingly, of applied models.

Table 3. Breakdown of growth in the United States and France.

	1990-1995		1995-2000	
	United States	France	United States	France
Capital	1.25	1.28	2.27	1.37
(of which ICT)	(0.55)	(0.28)	(1.11)	(0.60)
Labour	0.86	0.05	1.30	0.54
Global productivity of factors	0.23	-0.24	0.63	0.74
Added value	2.35	1.09	4.2	2.65

Source: Debonneuil and Fontagné (2003)

2. The endogenisation of technical progress in the models

The consideration of innovation as a factor in explaining growth is not new to economic analysis. According to Guellec (1999), it goes back at least as far as Adam Smith (1776) and is clearly found in Karl Marx (1867) and Joseph Schumpeter (1911). Since the 1960's, growth theories have been constantly reviewed to bring them in line with the stylised facts. From exogenous technical progress to the innovation of processes and products, arising out of companies' investment choices, all these theories emphasise the vital role of technical change in determining the rate of growth in economies. By endogenising technical progress in the growth models, we are able to explain technical progress as economic behaviour that, up until then, had fallen like manna from heaven. Furthermore, as we will see in section 2.1, endogenous growth models have rehabilitated economic policies. Since the end of the 1990's, applied models, and especially certain balanced models, have started to be enhanced by endogenous innovation mechanisms . Nemesis is one of the few macro-econometric models to incorporate such mechanisms. In section 2.2 we present the way in which technical progress was made more endogenous.

2.1. New growth theories

Growth theories developed in the 1960's, following on from the work of Solow and Swan, which was published in 1956. Their models showed that the long-term economic growth rate is determined by the intensity of technical progress and an increase in the working population, both of which are exogenous. As a result, no economic policy can influence the growth rate. According to empirical research into his measurement, the "Solow residue", defined as technical progress incorporated into production, explains at least 50 % to 80 % of economic growth on its own. This shows the importance of technical progress as a growth factor. However, these measurements highlight the main defect in that generation of growth models: the lack of explanation of technical progress itself. Theories of endogenous growth arise out of a desire to incorporate economic behaviour into the origin of technical progress in the models.

Early theories of endogenous technical progress appeared nearly 25 years before endogenous growth theories. In 1962, Arrow published a learning model (*learning by doing*) that linked the global productivity of factors to experience (represented in the model by accrued gross investment). In the heterodox movement, Kaldor and Mirrlees (1962) rejected the use of the production function and, the same year, suggested a technical progress function. However, new growth theories appear in P. Romer's article of 1986.

To clarify the reasons for technical progress, endogenous growth models integrate private investment into physical capital, technological innovation, human capital or public capital as sources of technical progress. Unlike traditional models, in which returns to scale are decreasing[40], the new growth models assume increasing returns. These are due to the explicit inclusion of the role of knowledge, which accumulates over time. Knowledge comes from invention, which comes from research. The result is innovation, as long as the market and the company's means permit it (Boyer, Didier, 1998). This permeates into the economy and leads to further innovation. The stock of knowledge is increased still further. Systems for protecting innovation, such as patents or secrecy, only serve to postpone this increase in the stock of knowledge, from which all companies benefit. This what led Bernard de Chartres to say in the 12th Century, and then Newton, that, "we are hoisted on to the shoulders of giants". This is why the economy benefits from positive spillovers at the start of increasing returns to scale[41]. Thanks to this property of the economy, economic policies have rediscovered their influence on economic growth.

2.1.1. The inclusion of spillovers

In addition to the research that they carry out themselves, innovative companies benefit from spillovers linked to the fact that knowledge is a cumulative asset and, in the absence of protection through secrecy or a patent, a non-rival and partially exclusive one. Knowledge is non-rival as it may be used by several economic groups at the same time and at virtually nil cost. This property encourages incentives to imitate an invention. Knowledge is also partially exclusive as there is nothing to prevent a competitor from using a company's invention to help towards other inventions or simply stimulate internal research. Spillovers explain why the private return on an invention is lower than its company return. Innovation produces effects in the company, but the distribution of the innovation via a range of channels (patents, scientific literature, exchanges of expertise, employee exchanges and exchanges of assets between firms or nations) will produce further, highly significant effects that will increase the returns on research to the point that they may become non-decreasing.

Jones and Williams (1997) and Cameron (1998) identified four types of spillovers operating within the economy:

— Technological spillovers due to the circulation of knowledge, patenting or movement of the labour force: these spillovers may be between companies, between sectors or international.
— Surplus transfers: even in the absence of spillovers, the innovator cannot hold on to all the company gains engendered by an innovation, especially because of the price reductions that it may lead to. The size of the appropriation of the gains depends on the structure of the market (Griliches, 1992).
— The third spillover is a negative one: it is the result of Schumpeter's creative destruction process (Aghion and Howitt (1992)): new ideas accelerate the displacement of former production processes, which leads to losses.
— The congestive effects linked to the interrelation between innovations: if innovations can be substituted, this spillover is negative as it leads to a duplication of R&D effort. In this case, one could achieve virtually the same research result with less R&D and a broader distribution of the innovation. However, if innovations complement each other, the spillover is positive as each innovation increases the profitability of the others. Dasgupta and Maskin

[40] In exogenous growth models, the marginal productivity of physical capital decreases with time, which generates a decrease in returns of scale.
[41] Spillovers are engendered by investment in physical capital in the 1986 Romer model; they stem directly from the sector of research into equipment assets in the 1990 model, and from the innovation of quality in the 1997 Aghion and Howitt model.

(1987) admit that innovations can be substituted, while David (1985) and Katz and Shapiro (1994) opt for the idea that innovations complement each other.

A large number of studies show the importance of these spillovers between companies, sectors and nations, which explains the very significant difference between the private profitability and public profitability of R&D (Cameron, 1998, Bagnoli, 2002). For the period between 1980 and 1996,Guellec and van Pottelsberg (2001) show evidence of the triple influence of R&D on the global productivity of factors:

— In the long term, company R&D increases the global productivity of factors by an elasticity of 0.13. This elasticity is equivalent to the private return on R&D[42]. It tends to increase with time, which is a sign of the growing importance of innovation in company strategies, and with the R&D intensity of companies, a factor in absorbing the knowledge of other companies. According to the OECD (2000), an increasing number of companies are going to external sources for innovation. More and more, companies are cooperating with other companies, buying equipment assets, using specialist services with a high knowledge content, entering into relations with scientific establishments, incorporating other companies or *start-ups* through mergers and acquisitions, and using highly qualified human resources from other sectors.
— Public R&D also has a positive influence on productivity, with long-term elasticity between Government and university research and productivity estimated at 0.17. Here again, the influence is stronger where companies' R&D intensity is higher.
— In the long term, foreign R&D is linked to the global productivity of factors by an elasticity that varies between 0.45 and 0.5. The circulation of knowledge therefore has more repercussions in terms of productivity that national R&D, as long as countries have a sufficient capacity for absorption. Innovation and technological change in small countries comes mainly from foreign R&D. On the other hand, the United States gains only a small benefit from foreign R&D.

2.1.2. The rehabilitation of economic policies

The possibility of using economic policy to act on the growth rate of the economy depends on the nature of returns to scale. Where, in traditional models, decreasing returns to scale prevent any action on the growth rate, non-decreasing returns to scale make it possible to increase the growth rate in endogenous growth models.

In exogenous growth models, in the traditions of the Solow model, the growth rate of the economy is determined by two exogenous parameters: the growth rates of population and technical progress. In order to favour long-term growth we need to develop investment in capital and (or) R&D. However, the accumulation of these factors is subject to the law of diminishing returns, which halts the process. Investment in capital generates a reduction in the marginal productivity of capital, which, inevitably, ends up lower than the interest rate. It is therefore no longer of interest to economic groups to place their savings in this type of investment, and the accumulation of capital is halted. The growth rate of the economy cannot therefore be sustainably increased.

In endogenous growth models, the possibility of non-diminishing returns on production factors[43] means that the accumulation process is not halted. By acting on the savings rate or on R&D effort, economic policy encourages the accumulation of capital and R&D and thus alters the long-term growth rate.

[42] The global productivity of factors partially takes into account the effects of R&D on production; elasticity is therefore equivalent to a return that is added to the remuneration of capital and labour.
[43] To simplify, by referring to a single-sector model, if the exponents of accumulable factors is greater than or equal to the unit in the production function, we find ourselves in a case of endogenous growth. The long-term growth rate is is therefore no longer exogenic, i.e. dependent on the population growth rate and on technical progress (exogenous), but will depend on the behaviour of economic groups (savings, investment, accumulation of R&D,…).

The non-diminishing returns assumption is at the heart of such issues in both theoretical and economic policy terms and, as such, has been the subject of a great deal of discussion and attempts at empirical validation.

One of the controversial issues[44] concerned the scale effect by which the growth rate of an economy depends on its size, i.e. its population. A number of solutions have been envisaged in the face of this obviously counter-intuitive property. Jones (1995), for example, developed “semi-endogenous» growth models. In these models, the innovation cluster that follows on from a major innovation, such as the steam engine or ICT, is characterised by an innovation probability that tends to reduce with the number of innovations. R&D returns are therefore diminishing. Segerstrom (1998) and Kortum (1997) constructed models with two innovation sectors (quality, variety) that retain the properties of endogenous growth while eliminating the effect of scale. Kremer (1993) believed that global trade forces us to adopt world population as the only variable of scale.

Studies aimed at validating the theory of non-diminishing returns of scale have generally consisted, not of quantifying returns, but of verifying the consequences of the theory for endogenous growth (Cameron, 1998, Temple, 1998, Bagnoli, 2002). Bean (1990) and Ireland (1990), for example, use Granger’s causality tests to show that the endogenous growth model is more probable than the traditional model. Similarly, Kocherlakota and Yi (1996) and McGrattan (1998) prove the superiority of the non-diminishing returns model.

The possibility of having an effect on the long-term growth rate also gives considerable scope for the use of structural growth policies (tax, grants and subsidies, infrastructure expenditure) and of course of policies linked to R&D effort. To achieve the Barcelona objective, we can also consider introducing macro-economic policies to construct an environment favourable to innovation, and innovation policies, such as the protection of intellectual property rights, increases in public-sector orders or the government grants for R&D envisaged in the European Commission action plan in 2002.

2.2. Incorporating technical progress into Nemesis

The endogenisation of technical progress in applied models is a very recent phenomenon. It has mainly been used in overall balance models. Some of these models follow on from the work carried out by Arrow (1962). Here, the rate of technical progress is linked to expertise or experience, measured by gross accumulated investment. They therefore take up a similar viewpoint to the AK model in which the capital K variable contains information relating to the state of the technology. This approach has been adopted in certain models relating to climate change, such as those of Goulder and Mathai (2000) and Grubb (2000). In this field, the characteristics of technologies are often linked to experience curves. Making technical progress endogenous provides a more effective, immediate implementation of policies to fight against greenhouse gases as a result of the experience acquired in the field.

Other overall balance models use R&D expenditure to make technical progress endogenous. This is the case in models dealing with issues relating to international trade (such as those of Diao and Roe (1997), Baldwin and Forslid (1999) and Diao *et alii* (1999)) and in des models applied to the environment and climate change (such as Nordhaus’ RDICE model (1999) or Fougeyrollas *et alii’s* GEM-E3 model (2001)). Endogenisation through R&D expenditure is not easy. The first difficulty comes in calculating the relationship between R&D and process or product innovations. The second comes from the possibility that there may be a number of balances. The third stems from the diversity of R&D levels of intensity and results in the sectors. Only a few sectors, such as those linked to ICT and the pharmaceutical sector, are R&D-intensive. It is therefore necessary to adopt a detailed sector-based approach so that the

[44] It has given rise in particular to econometric studies on the value of exponents of factors in the production function.

endogenisation of technical progress is appropriate. Few models manage to overcome this difficulty.[45]

Econometric models containing technical progress mechanisms endogenised by R&D are rare. To our knowledge, only the International Monetary Fund Multimod model, which is highly agglomerated, includes R&D stocks at a sector level. The Nemesis model takes it place in this new family of macro-econometric models with endogenous technical progress.

Table 4: Nemesis' sectors

1.	Agriculture	16.	Food, drink and tobacco
2.	Coal and coke	17.	Textiles, clothing and shoes
3.	Oil and gas extraction	18.	Paper and printing
4.	Gas distribution	19.	Plastic and rubber
5.	Refined oil	20.	Other manufactured goods
6.	Electricity	21.	Construction
7.	Water	22.	Distribution
8.	Ferrous and non-ferrous metals	23.	Accommodation and catering
9.	Non-metal ore products	24.	Transport on land
10.	Chemicals	25.	Air and sea transport
11.	Metal products	26.	Other forms of transport
12.	Agricultural and industrial machinery	27.	Communication
13.	Office machinery	28.	Banking, finance and insurance
14.	Electrical goods	29.	Other commercial services
15.	Transport equipment	30.	Non-commercial services

Nemesis is a detailed, sector-based econometric model that currently focuses on fifteen European countries and will be gradually extended to other countries (United States, Japan and Europe of 25). Such a level of breakdown (thirty activity sectors, Table 4) is essential if we are to properly describe structural phenomena and, particularly, medium and long-term changes: for this objective, the sectors are relatively contrasting from the point of view of growth and employment. Branch activities are interdependent due to exchanges of goods and transfers of technology between them.

The special feature in Nemesis is the endogenisation of technical progress across three phases: from R&D to the stock of knowledge, from the stock of knowledge to innovation and from innovation to economic performance.

2.2.1. The stock of knowledge

The variable that plays a vital role in the endogenisation of technical progress in Nemesis is the variable "knowledge" (KNOW) that arises out of the R&D stock. A sector's R&D stock is determined by its R&D expenditure and by a constant displacement rate. It is constituted as a stock of capital, with displacement being the gradual deletion of knowledge (figure 1).

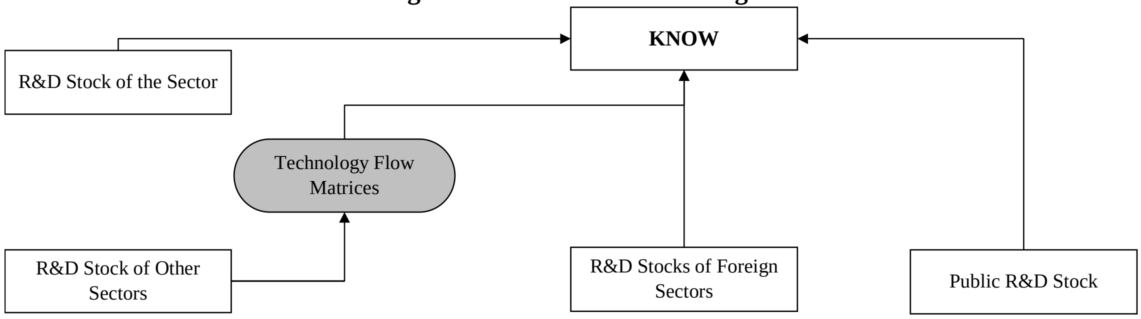
Figure 1: From R&D expenditure to the R&D stock

"Knowledge" is not determined only by the sector's R&D stock but also by all the knowledge spillovers in all national and foreign sectors (figure 2). Knowledge spillovers from other sectors are dependent on their stocks of R&D, via technological flow matrices. These matrices, which are differentiated by sector and by country, are constructed according to the methodology developed by Johnson for the OECD (Johnson, 2002). This consists of identifying, for every patent registered at the European Office, the sectors producing and using the innovation described in the patent. This is then used to determine the proportion in which the knowledge accumulated in a sector will benefit others, by calculating knowledge transfer coefficients, the knowledge being, by assumption, borne by the patents. This work is done in great detail (over 100 sectors) and the results are re-agglomerated in Nemesis' sector-based

[45] In addition, detailed models become very heavy to handle, which leads particularly to difficulties in resolving ideal forecast models (or rational in a stochastic world).

nomenclature in the form of technological flow matrices. “Knowledge” also feeds on the R&D stock in foreign sectors and on the public sector R&D stock.

Figure 2. The stock of knowledge



2.2.2. From stock of knowledge to innovation

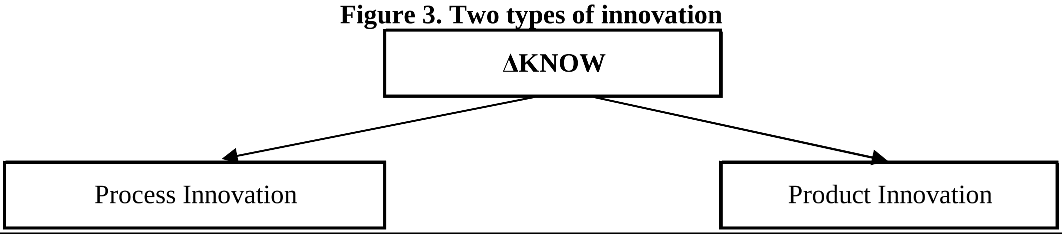
Innovations are determined by the variant in the stock of knowledge (figure 3). The two types of innovation are considered here:

— process innovations that increase the global productivity of factors in the specification that we have chosen;

— product innovations, which, in the fixed nomenclature of national accounting that underpins Nemesis, are shown in quality improvements.

These two types of innovation act very differently on economic performance: .

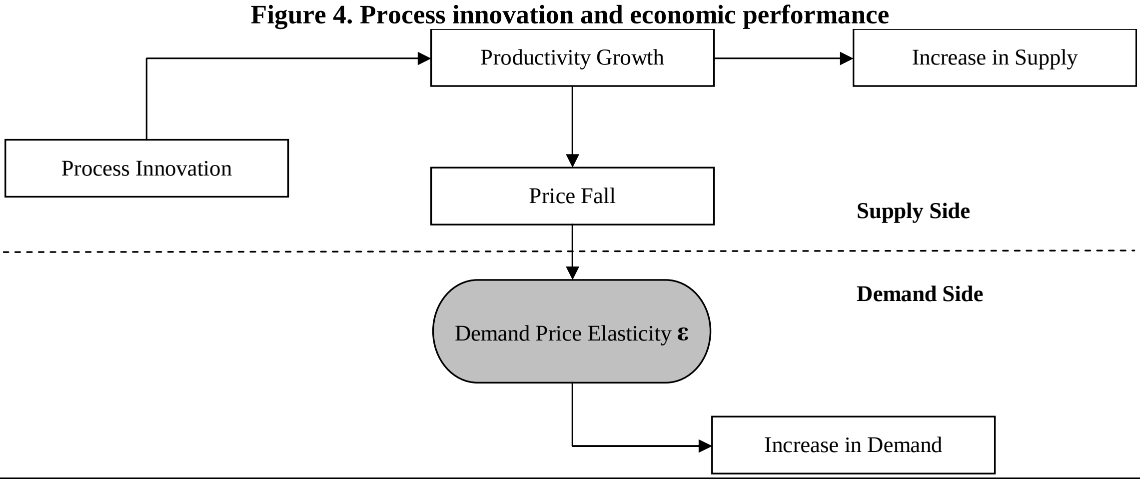
Figure 3. Two types of innovation



2.2.3. From innovation to economic performance

Process innovation does not lead to the same effects as product innovation. Process innovation increases the global productivity of factors, thus increasing product supply and reducing the unit production cost, and therefore the price. This price reduction leads to increased demand, which is dependent on demand price elasticity (figure 4).

Figure 4. Process innovation and economic performance

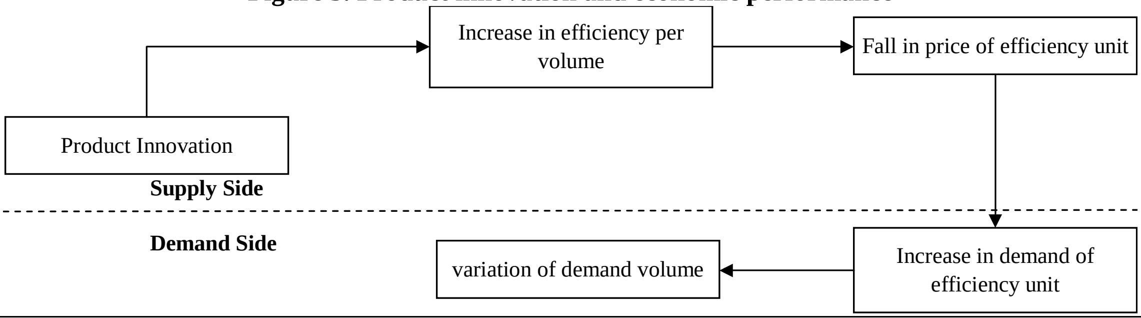


Growth in demand helps to absorb extra supply (at a constant usage level) if demand price elasticity is higher than or equal to one. However, econometric estimates in chronological series reveal an elasticity generally lower than one for each sector, and thus for the whole economy.

This result comes from the assumption of a representative firm per sector: we do not consider the innovative firm in competition with the other companies in its activity sector. This amounts to assuming that all firms in the sector innovate and reduce their prices. Increased demand then depends on the capacity for absorption represented by elasticity lower than one. In this case process innovation reduces the use of factors as the effects of supply outweigh the effects of demand.

Product innovation acts like an increase in efficiency per volume unit and increases demand for units of efficiency (figure 5). Volume production is only maintained if the increase in demand for the new efficiency is just equal to the increase in efficiency due to innovation. Generally, product innovation does more than compensate for the fall in factor usage due to process innovation. R&D therefore leads simultaneously to an increase in GDP and in the use of factors.

Figure 5. Product innovation and economic performance



The *ex ante* effects of innovation on GDP depend on the effects of the increase in knowledge on the global productivity of factors and on quality and thus on demand: increased production is in fact linked to increases in demand arising from process innovation and quality innovation respectively (box 1).

Box 1. The effects of innovation on economic performance

→ Process innovation: the accumulation of knowledge (KNOW) generates an increase in the global productivity of factors (TFP).

$$\frac{\Delta TFP}{TFP} = a\frac{\Delta KNOW}{KNOW}$$

→ Product innovation: the accumulation of knowledge (KNOW) leads to an improvement in quality (QUAL).

$$\frac{\Delta QUAL}{QUAL} = a'\frac{\Delta KNOW}{KNOW}$$

→ Economic performance: increased production (Y) depends on increased demand due to innovation.

$$\underbrace{\frac{\Delta Y}{Y}}_{\text{Accroissement de production}} = \underbrace{\varepsilon\frac{\Delta TFP}{TFP}}_{\text{Accroissement de demande dû aux innovations de procédé}} + \underbrace{\varepsilon'\frac{\Delta QUAL}{QUAL}}_{\text{Accroissement de demande dû aux innovations de produit}}$$

i.e. $\frac{\Delta Y}{Y} = (\varepsilon a + \varepsilon' a')\frac{\Delta KNOW}{KNOW} = \beta\frac{\Delta KNOW}{KNOW}$

Finally, economic performance, measured by increased production due to increased knowledge, is written as follows:

$$\frac{\Delta Y}{Y} = \beta\frac{\Delta KNOW}{KNOW}$$

Most of the available econometric studies link increased production with an increase in R&D stock (SRD) using the following formula[46]:

$$\frac{\Delta Y}{Y} = \alpha \frac{\Delta SRD}{SRD}$$

The difference between these two approaches is an explicit integration of all the spillovers in the first and an implicit or nil integration in the second.

Econometric studies (Mohnen (1990), Mairesse and Sassenou (1991), Grilliches (1992), Nadiri (1993), Cameron (1998), …) reveal a fairly broad range for parameter β of 0.05 to 0.2. The results are independent of the methods chosen. However, where β is estimated using instant cross-section series (inter-companies), it is higher than when chronological estimates are used (cf. section 1.1).

These results lead us to present a number of scenarios for the effects of the Barcelona policy according to the value chosen for parameter β. β's broad range of variant, allied to the results' sensitivity to its value requires an in-depth sensitivity analysis. We look at a set of assumptions concerning R&D policy itself, according, in particular, to how it is financed.

3. An evaluation of R&D effort policies[47]

The objective set in Barcelona to achieve an R&D intensity of 3 % of GDP in 2010 throughout Europe implies that the strengthening of the R&D effort is to be carried out with a certain convergence between the various European states. Major differences in intensity in 2002, in particular between the countries of Southern and Northern Europe (Cf. graph 5), with a minimum intensity of 0.67 % for Greece, and a maximum of 4.27 % for Sweden, must be gradually reduced to enable every country in Europe to play a full part in introducing "the world's most competitive and dynamic knowledge-based economy, capable of sustainable economic growth accompanied by quantitative and qualitative improvements in employment and greater social cohesion".

In the Nemesis model we have shown this need for convergence in research efforts between European States by choosing a distant date, 2050, by which we have assumed that every country in Europe will have achieved an R&D intensity of 4 % of GDP.

For 2010, we have chosen the objective of an average 3 % of GDP in Europe; however, by this date, convergence between European States remains relative, as the southern European countries are still catching up on the more advanced Northern countries.

To achieve a target of 3 % in 2010, then 4 % in 2050 for R&D intensity in Europe, R&D needs to grow more sharply between 2003 and 2010 than in the following years. We have therefore assumed that, between 2003 and 2010, every country will increase its R&D intensity in such a way as to achieve (virtually) the level of 4 % from 2017; in 2010, the research effort trajectory is then modified to obtain 3.5 % in 2030, then total convergence to 4 % of national intensities 2050.

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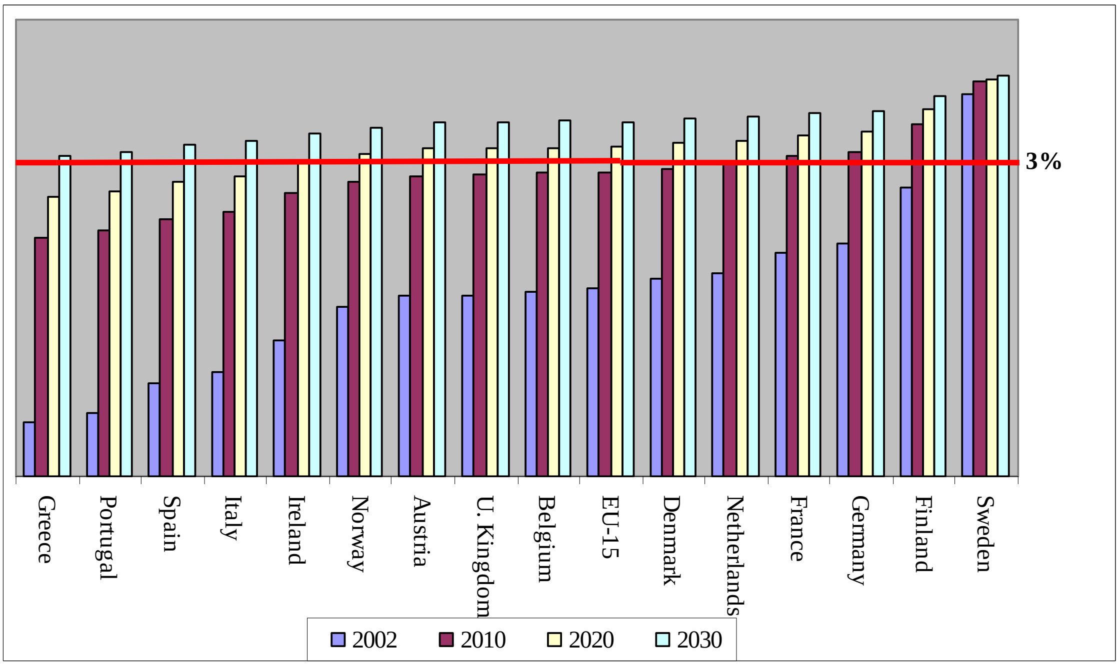
[46] The formula used for these calculations is $\frac{\Delta Y}{Y} = A(SRD)^{\alpha} F(K, L, ...)$. In theory, α is lower than β.

[47] The detailed results of the variants presented in this section are supplied in an attached report. Also, *below*, appendices 1 "A set of extra variants" and 3 provide a summary of all the key results for all the scenarios for Europe and appendix 2 "Results by EU-15+ country" provides the results for each country in the European Union.

Graph 5: Forecast R&D intensities in European countries for 2030



Also, in line with the Barcelona objective, we have assumed that a third of European research is financed by government in 2010, and that the remaining two-thirds is financed by private organisations. Beyond 2010, this distribution between private and government research effort is maintained.

With regard to where the research will take place, we have also chosen the assumption that the proportion carried out by private laboratories will gradually increase to reach two-thirds of R&D work across Europe and in each European State.

3.1. Mechanisms and implementation scenarios for R&D policy

We use a number of scenarios to surround the possible results of the European policy for increasing R&D effort,. We consider a set of assumptions, firstly with regard to the key parameters of Nemesis and, secondly, with regard to the R&D policy itself. A central variant (named $V_{0.0}$) has been chosen for an in-depth presentation of the results.[48] This scenario has appeared to be a median scenario in terms of both the mechanisms adopted and the policy implemented. All the variants are defined in relation to this basic variant by modifying either one of the model's operating parameters or a condition for implementing the policy.

3.1.1. A set of assumptions regarding Nemesis mechanisms

We study two mechanisms in the model in turn using sensitivity tests of the elasticity of economic performance in the stock of knowledge and the distribution of added value.

→ **Variant in elasticity β of economic performance with regard to the stock of knowledge.**

Elasticity β depend on both (see box 1) the link between R&D and innovation (coefficients *a* and *a'*) and the absorption of innovation (elasticities ε and ε'). As we have seen, the results of econometric literature are quite scattered (the value of β varies between 0.02 and 0.26). We assume that β is the weighted sum of a constant β_0 and a function of R&D intensity in each

[48] The variants are named $V_{i,j}$ with "i" the index relating to assumptions regarding the parameters of the model and "j" the index relating to the implementation of the R&D policy

sector, with this intensity increasing between 2002 and 2030.[49] In central variant $V_{0.0}$, we give greater weight to the constant than in variant $V_{1.0}$. Elasticity is therefore lower in 2030 than in the alternative scenario (Table 5). In a third variant $V_{2.0}$, we assume that elasticity β is identical in all sectors and all countries, and equal to 10 %.

Table 5. Change in β

	2002	2030
$V_{0.0}$	0.075	0.124
$V_{1.0}$	0.075	0.141
$V_{2.0}$	0.1	0.1

→ **Distribution of added value**

How are the productivity and growth gains engendered by innovation arising out of R&D shared out between companies and employees? The mechanism for determining salaries in Nemesis is based on a simple Phillips curve, in which the increase in actual salary as a result of growth is linked to tensions in the labour market. This assumption, which is admissible when productivity and growth gains are low, is no longer so when productivity gains are high and the timescale is a long one. We have therefore changed the original version of the Phillips curve, by including a productivity effect, and have constructed a variety of scenarii of sharing out added value.

— In scenario $V_{0.0}$, a third of productivity gains from work are passed on into actual salaries (a 10 % increase in the productivity of labour increases salaries by 3.33 %).
— In scenario $V_{4.0}$, productivity gains are totally retained by companies, who can pass them on in the form of price reductions, but salaries do not benefit from the gains and increase only according to tensions in the labour market. Growth is therefore "led" by gains in competitiveness in Europe and therefore by the external balance.
— In scenario, $V_{5.0}$, productivity gains are passed on into salaries in their entirety. Due to tension in the labour market, salaries increase *ex-post facto*[50] faster than productivity, which moves the distribution of added value in a direction favourable to employees. Here, consumption is the main vector of growth.

3.1.2. Variants for implementing the R&D policy

We set out several scenarios for R&D policy, which differ from the central variant in the assumption used for financing (public or private) R&D or in the assumption that part of the R&D effort is the result of public-sector orders placed in R&D-intensive sectors.

→ **The method used to finance research**

We consider two extreme scenarios in which most of the financing is borne by the government or by companies.

Where financing is assumed to be mainly by the government, the extra R&D intensity is financed in all sectors by government funds. The spontaneous increase in private R&D due to greater growth must, however, be paid for by firms. The public deficit for all European countries is therefore approximately 1.1 % of GDP *ex-ante*. The chosen assumption here is that the financing of expenditure operates through an increase in public deficit, without that deficit having any effect on the interest rate. This extra public expenditure will then act, at least at the outset, as a Keynesian multiplier.

Where private companies provide most of the financing for research, they also help to finance the public research effort, as the growth in public expenditure for research reaches only

[49] The determining equation β is $\beta = \alpha.\beta_0 + (1-\alpha)\, f\left(\frac{RD}{Y}\right)$

[50] We jointly separate out the *ex-ante* effects, before the model simulation, from the *ex-post facto* effects in the variants. The *ex-post facto* effects incorporate all the directs and indirect consequences of our scenarios as a result of the economic mechanisms in the model.

0.16 % of GDP in 2010, while the public R&D effort increases by 0.30 %. The financing of the effort results in a financing need, which, in the model's current structure, is passed on into company mark-ups, and therefore into the production price. This method of financing is therefore more inflationary than the previous one, which, as we shall see later, has the effect of limiting gains in competitiveness, and therefore growth and employment, compared to the alternative scenario.

Another method of financing by companies could have involved the banking and financial system, with increased R&D being financed by loans, in lines with provisions aimed at giving innovative firms easier access to credit. This is not possible in the current state of the model. However, the effect of such an assumption would have been limited. It would have led to a change in the timing of price increases, as the banking system would have helped to delay it.

→ **Public-sector orders**

The government needs R&D for its activities in defence, space exploration, environmental conservation and the production of goods and services (such as energy and aeronautics). It can approach the public research laboratories, such as the Atomic Energy Commission in France and the *National Laboratories* in the United States, but must also look to industry and approach companies like Dassault in France or Boeing in the United States. The Government is therefore faced with the alternative of having the R&D it needs carried out in public organisations or of approaching private bodies. The development of ICT in the United States is a good example of the knock-on effect of public-sector orders: initiated at the request of the American Defence Ministry, R&D in this area was highly beneficial to the private sector. The risks inherent in research into new technologies would certainly not have allowed such a development of the Internet if the American government had not been the leading client for these technologies.

We therefore consider a scenario in which the growth of R&D effort is the result of public-sector orders in sectors that are technologically advanced and R&D-intensive. If we increase the number of orders placed in these sectors, their R&D increases. So, even if R&D intensity in these sectors does not increase, the higher proportion of these activities in national economies will have the effect of strengthening R&D effort (by a simple structural effect).

This strategy cannot be considered for raising R&D effort to 3 % of GDP as this would assume too high a growth in public demand. We therefore couple this increased demand with an extra R&D effort to reach the objectives of the 3 % policy.

3.2. A benchmark scenario for the research effort in Europe

The following assumptions are retained for the central scenario[51]:

H1. Elasticity β of the stock of knowledge in economic performance : 0.075 in 2002 to 0.124 in 2030.

H2. Distribution of added value: one third of productivity gains from labour is redistributed to employees in addition to the increase in actual salaries due to tensions in the labour market.

H3. Financing of R&D: the private sector provides virtually all of the financing for the increased R&D effort; only 0.16 % of the extra effort in 2010 is provided by the public sector.[52] Two-thirds of all European expenditure on R&D is thus financed by the private sector in 2010.

H4. Who carries out the R&D? 70 % of the increased effort is carried out in the private sector, and the remaining 30 % is carried out in the public sector.

H5. Convergence: the assumption of total convergence is removed.

H6. Public-sector orders: no extra orders.

[51] The macro-economic results and those of certain representative economic sectors are given in the attached report.

[52] In 2010, R&D expenditure has increased by 1.14 % of GDP. The public sector finances 0.16 % of GDP and the private sector the remaining 0.98 %.

3.2.1. The macro-economic results: a two-phase increase in GDP and employment

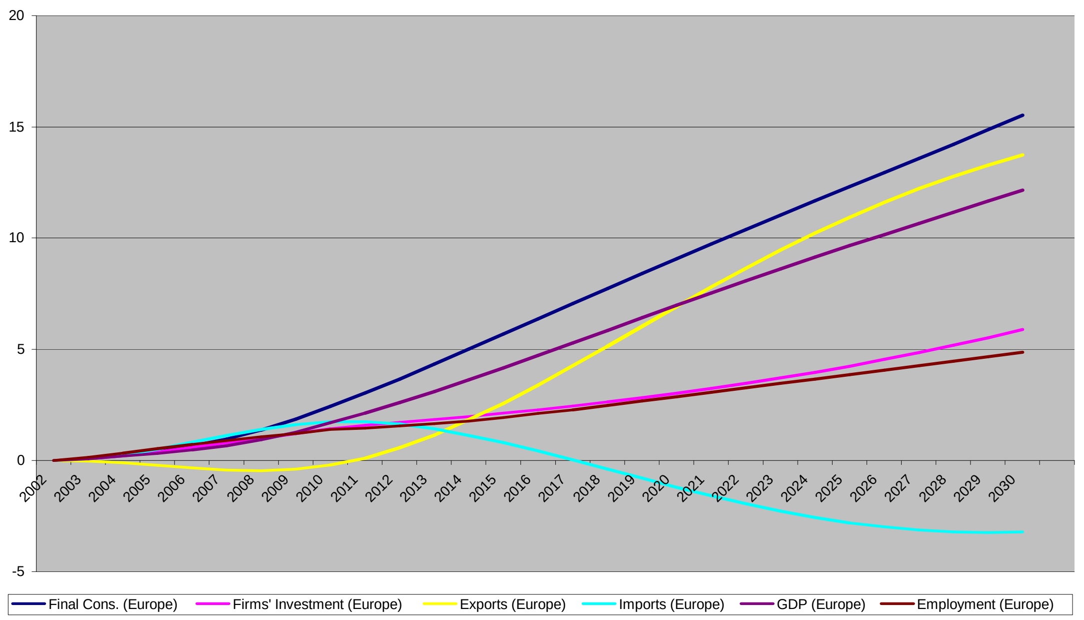
→ **Results for the whole of Europe**

- *The "multiplier" phase with external deficit*

Throughout the first phase, which runs virtually through to 2010, the European economy is "boosted" by the spontaneous increase in R&D expenditure. In 2010 the increase in GDP is 1.7 % for increased R&D expenditure of 1.1 % of GDP, which is equivalent to a multiplier (which has not yet reached maturity) of 1.6.

During this first period, R&D maturation times, which are 3 years for private R&D and 5 years for public R&D, are such that productivity goes up only slowly: the global productivity of factors increases by only 0.8 % in 2010. These low productivity gains explain the "multiplier" nature of the policy for increasing R&D expenditure.

Graph 6. Macro-economic impacts in Europe*



* As a % compared to the trend-based count

Increased GDP engenders increases in employment and real incomes, driven by the Phillips curve. Employment increases by 1.4 % in 2010 and real disposable income by 3 %. Up to 2008, growth in employment is greater than growth in GDP (graph 6), which, from a macro-economic point of view, may seem curious (employment normally increases long after GDP) but may be explained here by the high employment content of R&D expenditure.

All the internal demand headings increase. In particular, increased consumption, up by 2.4 % in 2010, plays a predominant role due to increases in employment and real incomes. Total investment is up by 1.8 % in 2010.

Price changes in this exercise differ from those seen in a standard Keynesian reflationary policy. In fact, 86 % of the financing of extra R&D in 2010 is provided by companies, who pass the extra cost on into prices. The inflationary character of the R&D policy is more pronounced than in a simple public expenditure policy. Prices thus increase under the concomitant influence of the boost to demand and the method of financing R&D expenditure. From 2008, productivity gains balance the cost of the policy for companies.

The boost to demand, combined with price increases, weighs on Europe's external trade: imports increase by 1.7 % and exports fall by 0.2 % in 2010. The external deficit therefore rises during this period, which explains the "relative" weakness of the multiplier, in spite of the low extroversion rate in the rest of Europe. In fact, only 10 % of European trade is carried out with the rest of the world. Nevertheless, from 2008, the external deficit decreases under the influence of a reduction in inflation.

- *The growth phase due to innovation*

Significant research efforts reach maturation from 2005. Beyond 2010, R&D will produce its full effects on the two forms of innovation: the global productivity gains of factors (from 0.8 % in 2010, 1.92 % in 2015, 3.11 % in 2020 to 5 % in 2030) and improvements to the quality of products (from 2.1 % in 2010, 4.96 % in 2015, 7.5 % in 2020 to 11.1 % in 2030). Growth is then led by increased demand due to falling costs, and therefore prices (see figure 4), and the quality effect (see figure 6).

This increased demand mainly affects two headings: consumption and external balance. Consumption goes up because prices fall and quality improves; within the Nemesis framework, on their own, price reductions due to an increase in the productivity of factors would not have been enough to lead growth. Similarly, imports and exports benefit from gains in price competitiveness and structural competitiveness. Exports grow sharply from 2011 while imports become negative once again (below the trend-based count) after 2018, which is an exceptional performance if we consider the strong growth that increases the demand for imports.

On the other hand, company investment, the corollary of final demand, increases less rapidly due to the gain in the global productivity of factors. Investment increases from only 2.1 % in 2015, 3 % in 2020 to 5.9 % in 2030. We should note that, over the long term, the capital coefficient tends to fall, which does not fit in with economic history and which long series relate. However, we are describing, here, a period in which R&D effort is constantly increasing, which takes us away from a stable situation trajectory.

Similarly, employment increases by only 4.9 % in 2030 (with 2.87 % in 2015 and 3.86 % in 2020), which is much lower than the growth of GDP, of 12.1 % in 2030 (6.97 % in 2015 and 9.65 % in 2020). In fact, labour also benefits from the effects of R&D. Labour productivity increases by 8.1 % in 2030. Europe creates 10 million jobs over the period, 3.1 million of which are linked to research (with respectively 3.1 and 2 million in 2015 and 5 and 2.4 million in 2020). The non-research employment figures are relatively low (up by 3.4 % in 2030) as growth is partly based on significant productivity gains. Certain sectors, as we shall see now, even lose some jobs despite fairly sustained growth. These results should not cause concern: they are actually consistent with sustained growth in a Europe that is affected by an ageing population.

Even though, at the end of the period, we see slight inflation due to labour force restriction phenomena (which lead to significant rises in actual salaries) GDP increases by 12.1 % in 2030, which is the equivalent of a surplus volume growth of just under 0.5 % per year. This growth corresponds to the volume of added value and does not include the extra quality, and therefore well-being due to the innovation policy. Consumption goes up by 15.5 % (5.7 % in 2015 and 9.1 % in 2020), exports by 13.7 % (2.6 % in 2015 and 6.9 % in 2020) and imports fall by 3.2 % (they increase by 0.8 % in 2015 and fall by 1.2 % in 2020).

Lastly, of course, the method of financing R&D effort does not increase the load on the budget and therefore on government deficit.

→ **National results**

In this section we analyse the macro-economic results for Greece, Belgium, France and Sweden. The choice of these countries is based on R&D intensity in the latest available year. Greece is the least advanced country (0.67 % of GDP in 2000), and Sweden is the most advanced (4.27 % of GDP in 2001), while Belgium (2.17 % of GDP in 2001) and France (2.23 % of GDP in 2002) are amongst the leaders[53].

[53] These R&D intensities have been updated for the requirements of the presentation and are not necessarily the same as those used with the Nemesis model.

Globally speaking, the macro-economic mechanisms operating in every country are the same as for Europe taken as a whole, but they vary according to the size of the catch-up effort required. The effect of the increase in R&D may be differentiated by the country's own characteristics, but it is the size of the effort that will determine gains or losses in the country's relative competitiveness compared to all the other countries in Europe, with the countries that catch up most improving their relative competitiveness.

The impact of expenditure at the start of the period is thus greater where initial R&D intensity is at its weakest: therefore, at the very start of the period, countries with a low intensity will see a greater rise in GDP but will lose in terms of relative competitiveness in comparison with other European countries. But increased productivity, and therefore relative competitiveness at the end of the period will be greater for those countries that have to do the most catching up.

- *The consequences for Greece (graph 7)*

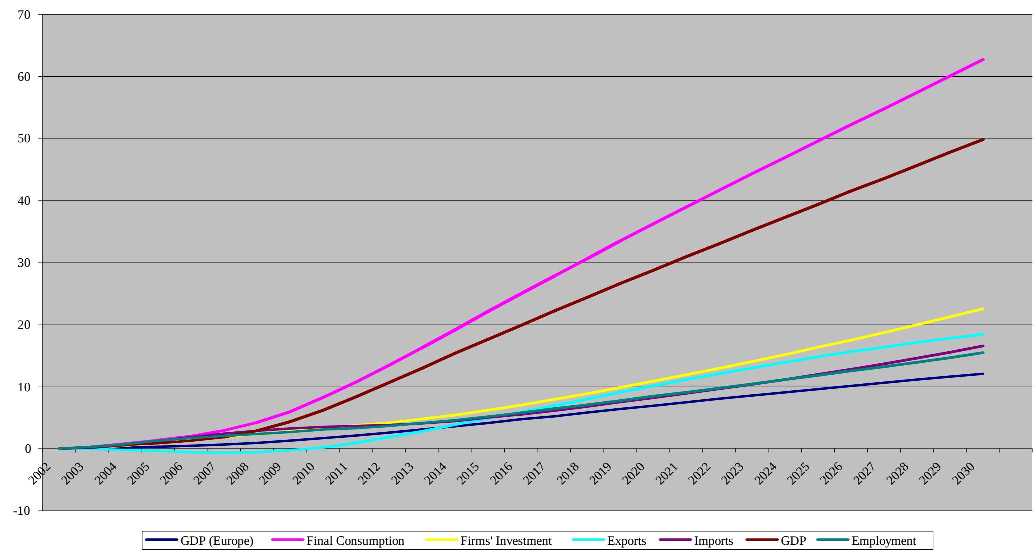
Greece benefits most from the R&D policy; it is the country that has to put in the most effort to catch up in terms of R&D intensity; the latter goes up by 0.67 % of GDP in 2002 to 2.37 % in 2010 then to 3.19 % in 2030. The initial impact, of 1.8 % of GDP in 2010, allows GDP to rise by 6.26 %, which is equivalent to a multiplier of 3.4.

The size of this initial impact leads to inflationary pressures higher than the European average during the first phase of the policy, despite a substantial increase in the global productivity of factors (2.7 % in 2010, though it is only 0.8 % for the whole of Europe). The high rise in employment and expenditure during the early years has a knock-on effect on all the demand headings and, finally, on growth. Nevertheless, the inflationary pressures of the early years leads to a contraction in Greece's exports vis-à-vis all its trading partners, both inside and outside Europe. It is important to note that Greece sees its intra-European exports increase from 2008, well before its extra-European exports. This illustrates the fact that Greece gains in competitiveness vis-à-vis its European partners, whose research effort increases more steadily.

During the second phase, the knock-on effects of the increased demand headings and, in particular, household consumption, are amplified by the role of product and process innovation[54], which engender significant gains in competitiveness. Greece's total exports increase by 18.5 % in 2030, with a 16.9 % increase in the number of outlets in the European market. Greece's imports also increase significantly due to a high rate of extroversion, but this increase is limited by the country's improved competitiveness, which reduces the import content of growth. GDP thus goes up by nearly 50 %, while imports grow by only 16.6 %.

[54] The product quality index and the total productivity of factors increase by 32.6 and 15.8 % respectively in 2030.

Graph 7. Macro-economic impacts in Greece*



* As a % compared to the trend-based count.

Finally, we should emphasise that Greece's growth is "led" more by the increase in household consumption than by improvements in its external trade. Firstly, the growth in employment (15.5 %) and household income is very high, which allows households to increase their consumption by 63 %; secondly, although the improvement in Greece's competitive position is very significant, it is taking place in a special situation in which the growth differential between the average for European countries and Greece, of the order of 1 to 4, is too great to keep to contribution of exports to GDP constant in the country.

- *The consequences for Sweden (graph 8)*

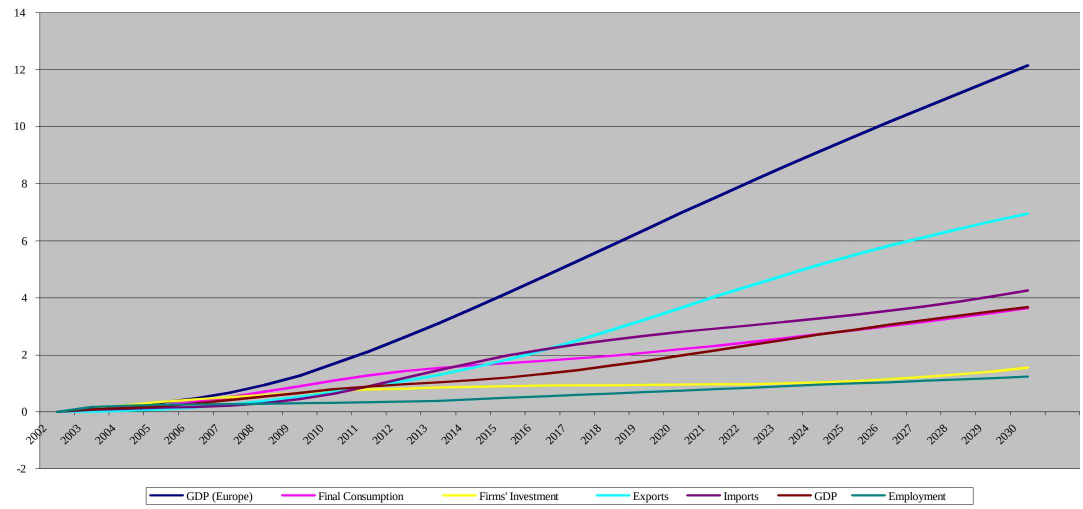
For reasons contrary to what is happening in Greece, Sweden is the European country that benefits least from increased European research effort.

The country's research intensity in relation to GDP is in fact the highest in Europe, which limits both the size of the reflationary effect and the improvement in competitiveness involved in the policy in this country. So the two growth phases that we have pointed up are less marked in Sweden than in the rest of Europe.

During the first phase of the policy, between 2002 and 2010, the weakness of the reflationary effect allows Sweden to maintain its level of competitiveness compared to that achieved by its main trading partners in Europe; on the other hand, its exports to the rest of the world are slightly reduced. Sweden's GDP rises by 0.79 % in 2010, which implies a multiplier of 1.7.

During the second phase of the policy, the productivity of factors and the product quality index increase only a little, with 2.2 % and 3.8 % respectively in 2030.

Graph 8. Macro-economic effects in Sweden*



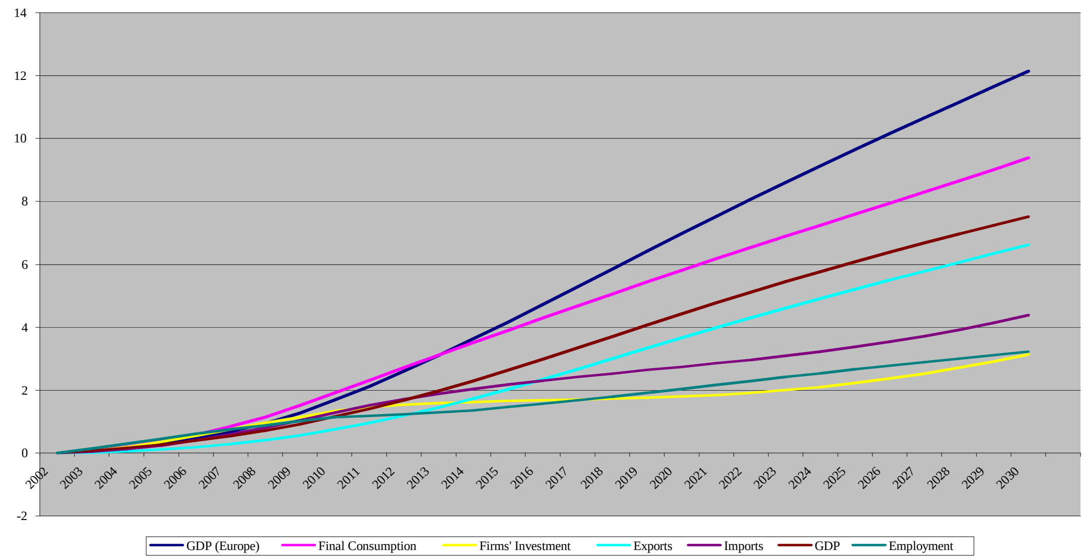
* As a % compared to the trend-based count.

Sweden's competitive position with regard to its European trading partners deteriorates; nevertheless, Sweden manages to increase its exports on the European market by 4.9 % in 2030, due to the favourable growth differential that is put in place for the country's external trade; Sweden's exports outside Europe also grow by 10.2 %, which allows total exports to grow by nearly 7 %, taking into account the structure of its external trade, which is more directed towards the rest of the world than in other European countries. In total, in 2030, Sweden's GDP gains only 3.67 %, which is the weakest performance of all the European countries, and the growth in job creation is limited to 1.24 %.

- *The consequences for Belgium (graph 9) and France (graph 10)*

R&D intensity in Belgium (2.17 %) and France (2.23 %) are situated at around 10 % above the European average (1.99 % in 2002). R&D intensity in these two countries increases to 3.5 % and 3.6 % of GDP respectively in 2030, involving a slight catch-up effort

Graph 9. Macro-economic effects in Belgium*



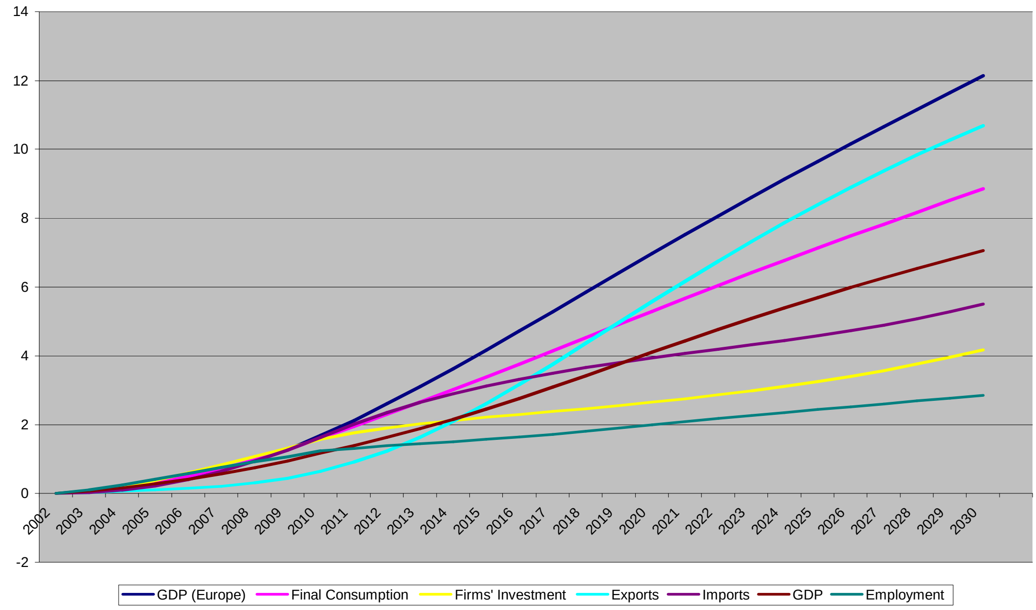
* As a % compared to the trend-based count.

by Belgium on France[55]; this is shown by slightly higher growth in the global productivity of factors and the product quality index in Belgium, avec 5.5 % compared to 3.5 % and 9.5 % compared to 7.7 % respectively in 2030.

At the end of the simulation period, the growth differential between the two countries is, however, more limited than is shown by the respective changes in their structural competitiveness, with a GDP progression of 7.5 % in Belgium and 7.1 % in France.

There are two phenomena at work to explain the latter observation; firstly, Belgium, which creates more jobs than France, with 3.2 % compared to 2.8 %, experiences more tensions in its labour market, which also brings down its level of price competitiveness via the model's mechanisms for indexing salaries to prices; secondly, Belgium's external trade grows less favourably than France's, with export growth of 2.3 % compared to 5.2 % in France, as Belgium is not as well positioned as France in a rapidly growing European market; Belgium's exports within Europe see only limited growth of 5.2 % compared to 9.4 % for France.

Graph 10. Macro-economic effects in France*



* As a % compared to the trend-based count.

- *Review of the results for all European countries (graph 11)*

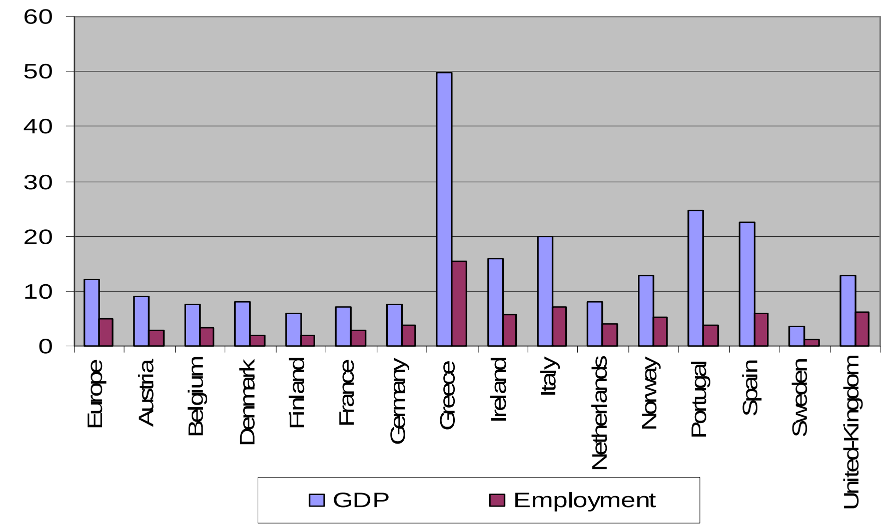
If we follow on from what we have just seen for Greece, Sweden, Belgium and France, we will observe that, for all the European countries, the results of the policy on GDP and employment in 2030 depend on the amount of catching up on GDP's R&D intensity. Countries that are initially the least R&D-intensive grow more; in the medium and long term, these countries will engender the greatest gains in productivity and therefore competitiveness.

GDP gains in 2030 are also greater in the countries of Southern Europe, with 24.7 % for Portugal, 22.6 % for Spain and 19.8 % for Italy. For other countries, they are between 5.9 % for Finland and 15.8 % for Ireland, with 7.6 % in Germany, 8.1 % in the Netherlands, 8.1 % in Denmark, 9 % in Austria, 12.7 % in Norway and 12.8 % in the United Kingdom.

Results by country for employment, research employment and government Budget Balance, for 2010 and 2030 may be found in appendix 2.

[55] In the Nemesis model in 2002 the difference in intensity between the two countries is in fact greater: 0.4 GDP points.

Graph 11. GDP and employment in European countries in 2030*



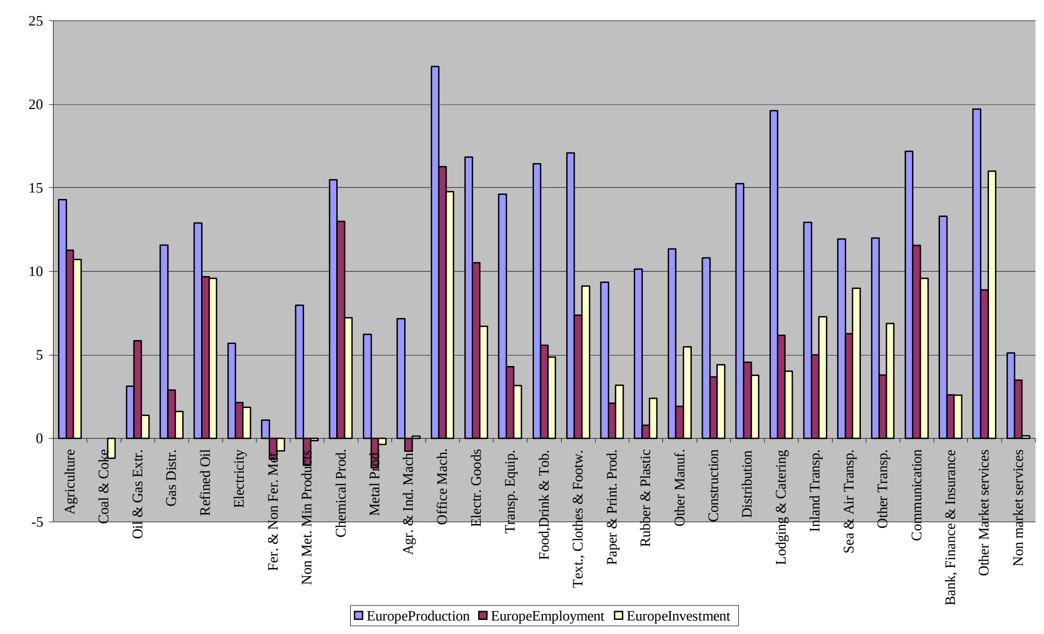
* As a % compared to the trend-based count.

3.2.2. Sector-based results

→ Results for Europe

Four groups of sectors can be picked out from the point of view of effects and results (Cf. graph 12): R&D-intensive sectors, intermediate goods sectors, investment goods sectors (not included elsewhere) and consumer goods sectors.

Graph 12. Production, employment and investment in sectors in Europe in 2030*



* As a % compared to the trend-based count.

Overall, we can see that sector-based changes are in line with those of the macro-economy (see, as an illustration, graph 13 for the electrical goods sector): the early years of maturation are marked by slower growth and a widening of the external deficit due to increased demand, which increases imports, and increased prices, which reduce exports and cause imports to rise even further. After this maturation phase, the process of growth due to innovation sets in, with its effects on final demand competitiveness. Generally speaking, production increases are much higher than increases in jobs, due to strong productivity gains.

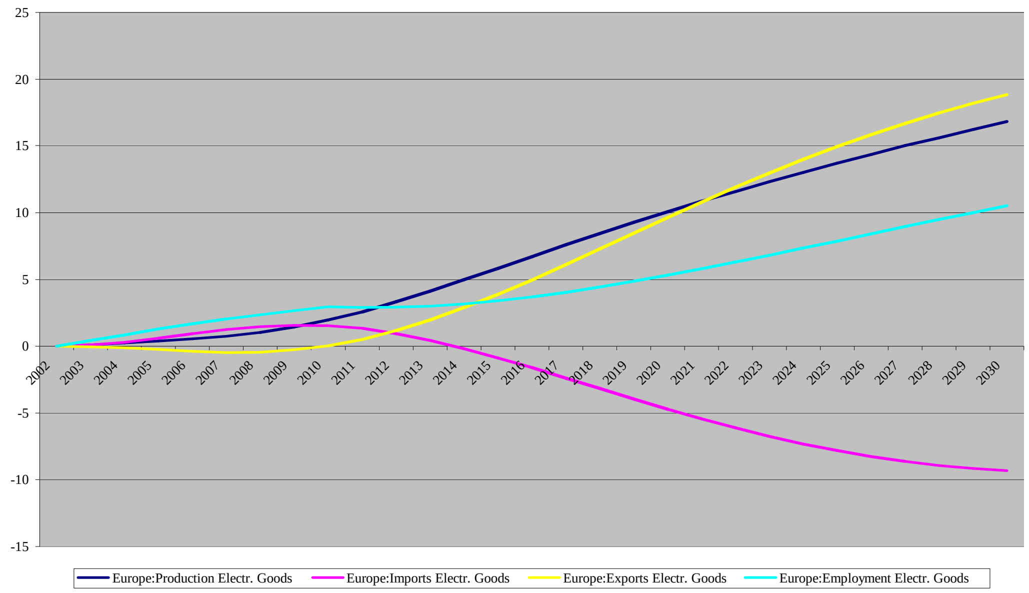
- *R&D-intensive sectors*

R&D-intensive sectors are those in which the productivity of knowledge, and therefore R&D, is the highest. These are the chemical industry, office machines, electrical goods and transport equipment. The other commercial services, which post R&D, which it is not in the manufacturing sectors (subcontracting of commercial research services), is another sector carrying out a lot of R&D.

All these sectors have a high production growth rate: in 2030 production increases between 14.6 % for transport equipment and 22.3 % for office machines. This growth is explained by the significant improvement in external balance over the period; the high rise in exports is in fact accompanied by an equally significant drop in imports. In the electrical goods, chemicals and transport equipment sectors (graph 13), where exports grow faster than production, gains in price competitiveness and structural competitiveness explain most of the changes.

This is also confirmed by the growth in internal demand for these R&D-intensive sectors, which is sustained despite the fact that they partially cover intermediate products, such as chemicals, equipment products, electrical goods and transport equipment. The fall in price due to the quality effect and productivity gains achieved thus feeds increased demand through substitution effects favourable to the goods produced by these sectors; the negative impact of this demand linked to productivity improvements in client sectors is therefore lessened.

Graph 13. The electrical goods sector in Europe*



* As a % compared to the trend-based count.

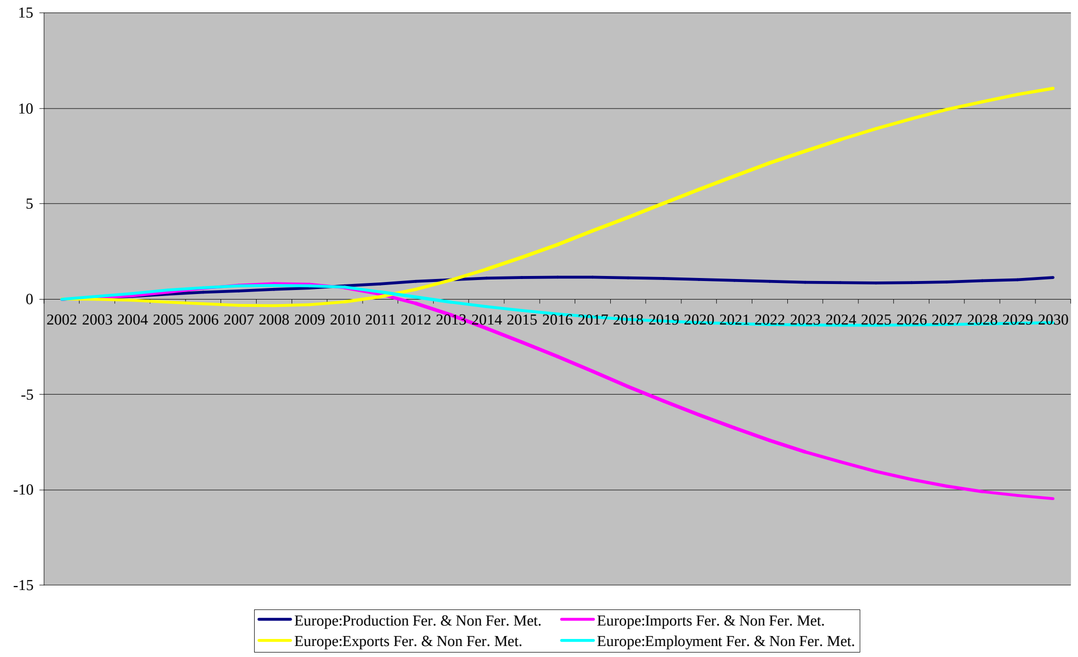
In the electrical goods sector, for example, demand for the needs of consumption, investment and intermediate consumption increase by 13.6 %, 9.5 % and 13.2 % respectively.

Employment in R&D-intensive sectors grows much less than production due to the strong productivity gains engendered by R&D. For example, in the electrical goods sector, production rises by 16.8 % in 2030 while employment rises by only 10.5 %; the reduced employment content of growth in this sector is explained by the overall size of productivity gains, with a 12.2 % progression in 2030. In this sector, with its high technological content, we can imagine a development method in which material production requires fewer and fewer jobs due to progress in terms of productivity and quality that is achieved by research activities which themselves are very job-rich. We are thus seeing jobs in R&D gradually taking over from jobs in production.

- *The intermediate goods sectors*[56]

These are the ones that suffer most from the R&D policy: progress in the global productivity of factors reduces demand for these products. As, in addition, the R&D content of the products is relatively low, quality improvements and manufacturing progress is not sufficient to give much of a boost to demand. Jobs are therefore slightly reduced (graph 14).

Graph 14. The ferrous and non-ferrous metals sector in Europe*



* As a % compared to the trend-based count.

- *Other investment goods sectors*[57]

These sectors should be differentiated from the investment goods sectors that carry out a lot of R&D and that see their outlets increasing due to the quality effect and productivity effect, so that employment increases; the latter are amongst the "R&D-intensive» sectors.

On the other hand, the sectors involved here suffer due to their low R&D intensity. Their limited gains in productivity and quality do not allow them to increase the level of demand for them as much as the average for the other sectors, in a context in which, in addition, their clients are themselves achieving significant productivity gains and reducing their investment levels. This is particularly the case for agricultural and industrial machinery (graph 15) whose production increases by only 7.2 % and which sees a very slight fall in the number of jobs (-0.8 % in 2030). However, the construction sector is an exception to the extent that much of the demand for it emanates from households whose purchasing power and invested savings are increasing considerably in Europe. Changes in this sector should therefore be compared more with what is happening in the consumer goods and services sectors.

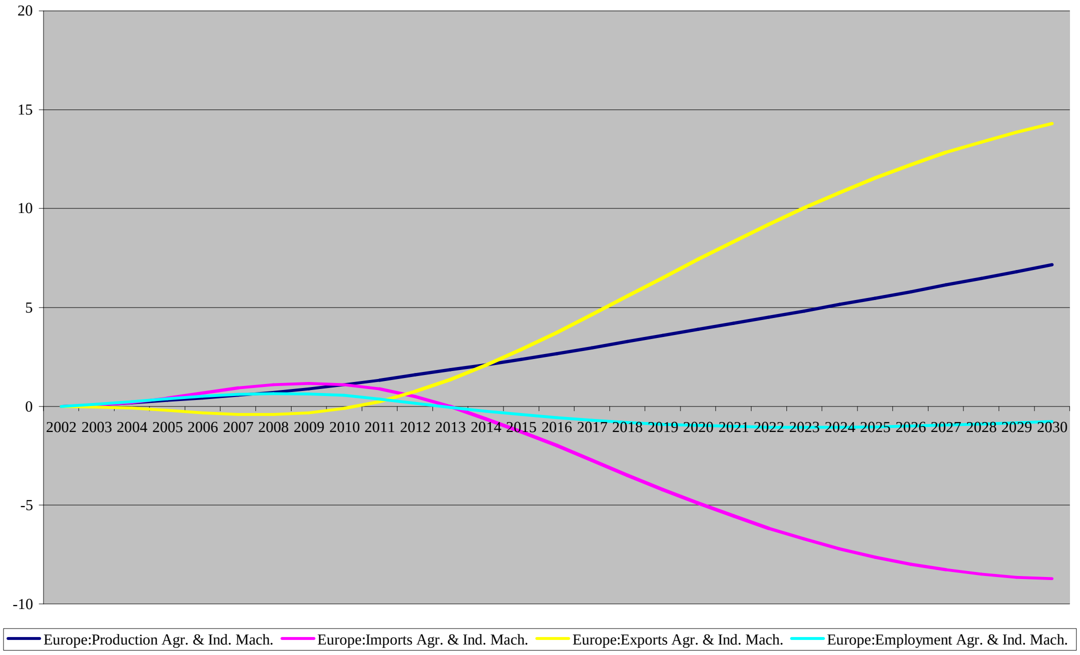
- *The consumer goods and services sectors*[58]

These sectors are favoured by both the strengthening of their R&D effort and the increase in actual salaries and, more generally, the purchasing power of households. The final consumption of households is thus a powerful driving force for the growth that finds its way into Europe, and

[56] This refers to ferrous and non-ferrous metals, non-metallic mineral products, metal products, rubber and plastics sectors. The chemical industry, which includes pharmacy, is one of the R&D-intensive sectors.
[57] This refers to machinery for agriculture and manufacturing, other industries and construction.
[58] This refers to sectors such as food, drink, tobacco, textiles, clothes and shoes, paper and printing products, accommodation, catering and transport services.

a number of consumer goods sectors see their production increase by over 15 %, with most of them exceeding 10 %.

Graph 15. The agricultural and industrial machinery sector in Europe*

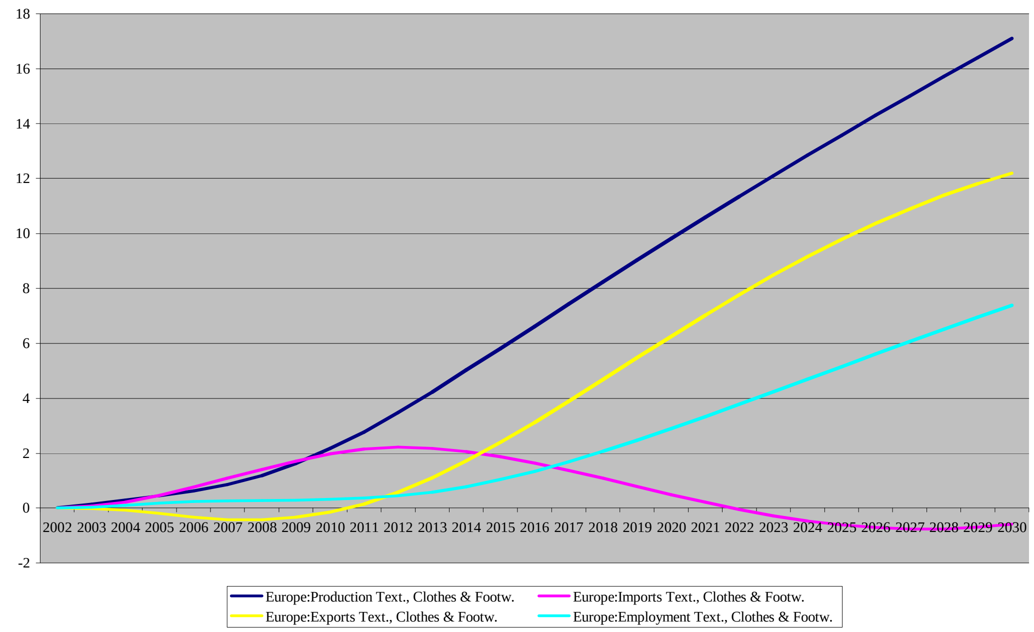


* As a % compared to the trend-based count.

The strong growth in employment in all the consumer goods and private services sectors is thus part of a virtuous circle, with growth in these sectors feeding on itself and bringing with it growth for every sector of the economy.

We therefore see that the policy of 3 % of GDP for research in Europe will radically change the contribution to growth of the various production sectors that go to make up the European economy. Favoured by significant improvements in productivity and the quality of their products, sectors with high technological intensity will win the largest market shares, followed by sectors that supply households with goods and services, who see their contribution to European growth stabilising or growing slightly; on the other hand, sectors supplying intermediate or investment goods to the production system, and which are at the same time not very R&D-intensive, will see their contribution to European growth being reduced.

Graph 16. The textiles, clothing and shoes sector in Europe*



* As a % compared to the trend-based count.

However, all European sectors gain in competitiveness vis-à-vis the rest of the world, where we have not assumed that an aggressive research policy has been introduced.

→ **National results**

At a national level, each sector will improve its competitiveness vis-à-vis the rest of the world, while European countries catching up on their R&D effort will see their relative competitiveness improve at a European level; let us look at this in closer detail.

- *R&D-intensive sectors*

These are the sectors in which changes in production, relative to other European countries, will depend the most on changes in the research effort; production increases in all countries, but least in Sweden, whose research intensity increases the least, and most in Greece, whose efforts to catch up with research are the greatest of all European countries.

This is perfectly illustrated by the example of the electrical goods sector (graph 17a). Production in this sector is practically unchanged in Sweden, in 2030 (0.3 %), while it increases by 28.7 % in Greece; in France and Belgium, progression is around 15 %. The changes seen in other R&D-intensive sectors are similar.

At a national and European level, the strong productivity gains achieved by R&D-intensive sectors explains why employment grows less quickly than production; the only exception the electrical goods sector in Greece, where employment and production increase by nearly 30 % (graph 17b); the strong employment content of research compensates here for the loss of jobs outside research activities.

- *Other sectors*

The intermediate goods sectors[59] see demand contracting under the effect of major productivity gains achieved by all sectors. In addition, certain countries, such as Sweden, suffer loses of market share in Europe, which are not always compensated by sufficiently large gains in market share outside Europe; in these countries, the structure of external trade by zone (inside and outside Europe) will dictate changes in the external balance for each intermediate sector.

[59] Excluding the Chemicals sector, which also includes Pharmacy.

Let us look more closely at the non-ferrous metals sector. In Belgium, exports in this sector fall back more than imports; in fact, internal demand contracts under the effect of productivity gains, leading to a fall in production (-3.6 %). The same mechanisms are at work in Greece, but in this country, which is significantly raising its research effort, significant gains in competitiveness mean that exports of non-ferrous metals increase by 14 %, where they fall back by 3.6 % in Belgium; in France and Sweden, they increase by 1.6 % and 0.4 % respectively. These changes thus reflect the redistribution of the structure of the European non-ferrous metals trade in favour of the Southern European countries, whose relative competitiveness improves (graph 18).

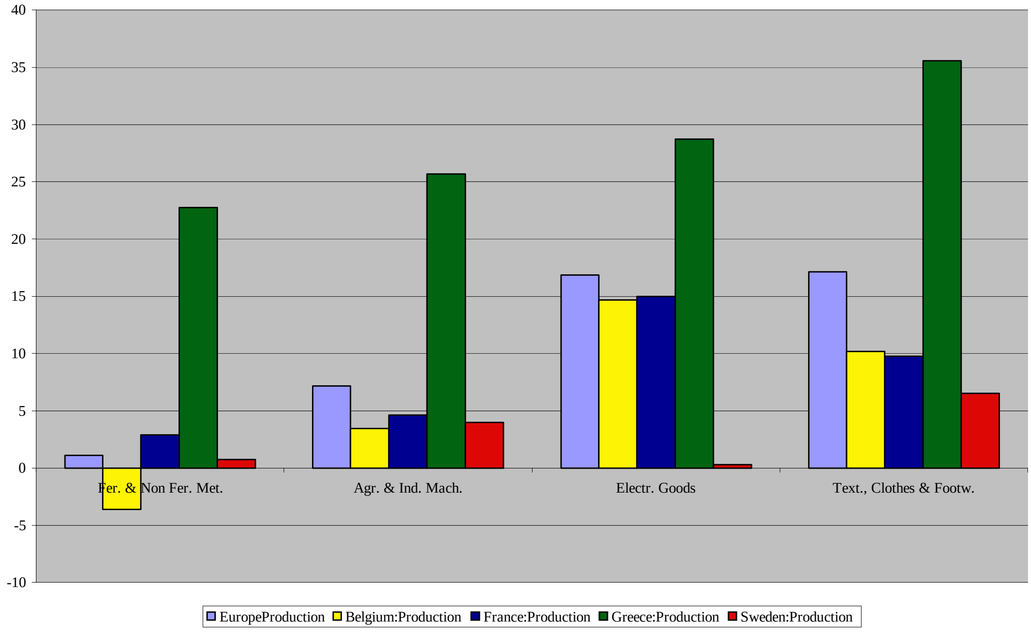
Employment in this sector tends to reduce in countries suffering the largest losses in terms of competitiveness (graph 17b); Greece, with a 5.6 % growth in the number of jobs, is the exception here, even though, due to strong productivity gains, this growth in employment is still well below that of production (+22.7 %).

The example of the non-ferrous metals sector could also be used to illustrate what is happening in an investment goods sector (not R&D-intensive) such as agricultural and industrial machinery. Innovation effort is generally not great enough to compensate for productivity gains in client sectors and maintain the level of demand and therefore production and employment; here again, only countries like Greece, who improve their relative competitiveness at a European level, manage to develop production and create jobs (graph 17b).

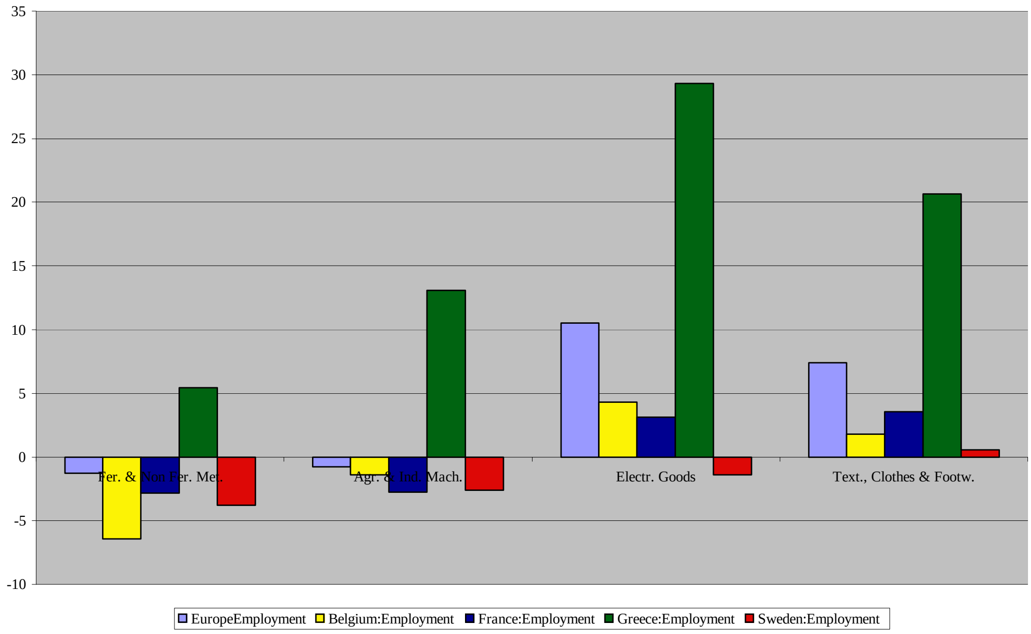
Amongst the less R&D-intensive sectors, it is the consumer goods and private services sectors that most improve their relative situation; the evaluation carried out above at a European level is also valid at a national level. These sectors benefit from the rise in household incomes, resulting, firstly, in economic growth, and, secondly, in the redistribution of a third of productivity gains to employees. The example of the textile and clothing sector perfectly illustrates the positive repercussions for employment and production (graphs 17a) of the favourable context that arises for these sectors; for production, progression in 2030 is between 6.5 % for Sweden and 36 % for Greece, with nearly 10 % for France and Belgium; the size of this progression by country reflects more the extent to which the purchasing power of households is improved rather than gains in competitiveness achieved within each national sector.

Graph 17. Production and jobs in 2030*

a. Production



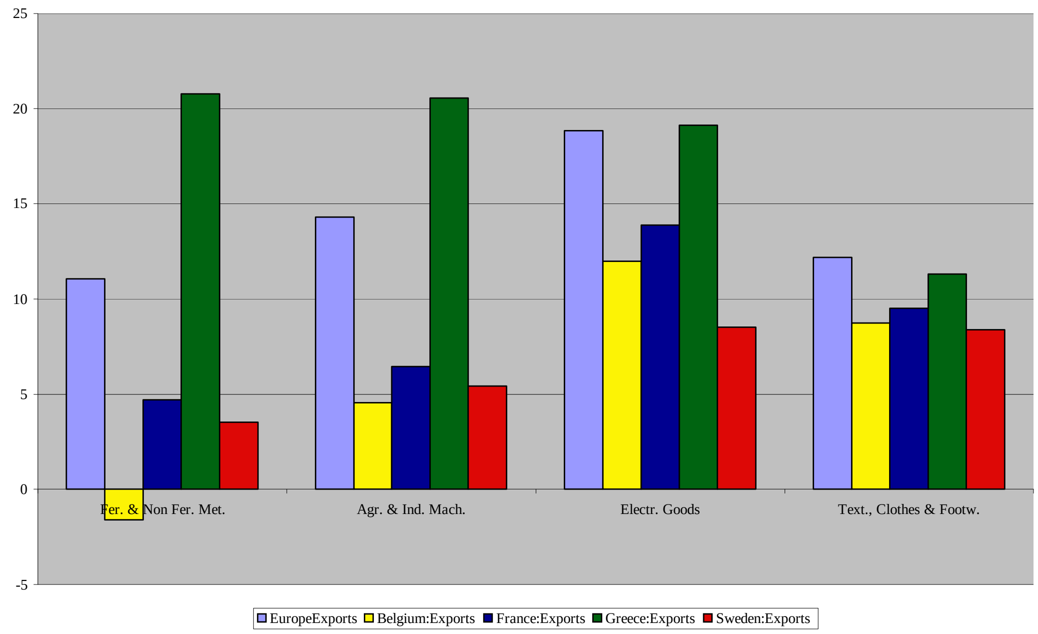
b. Jobs



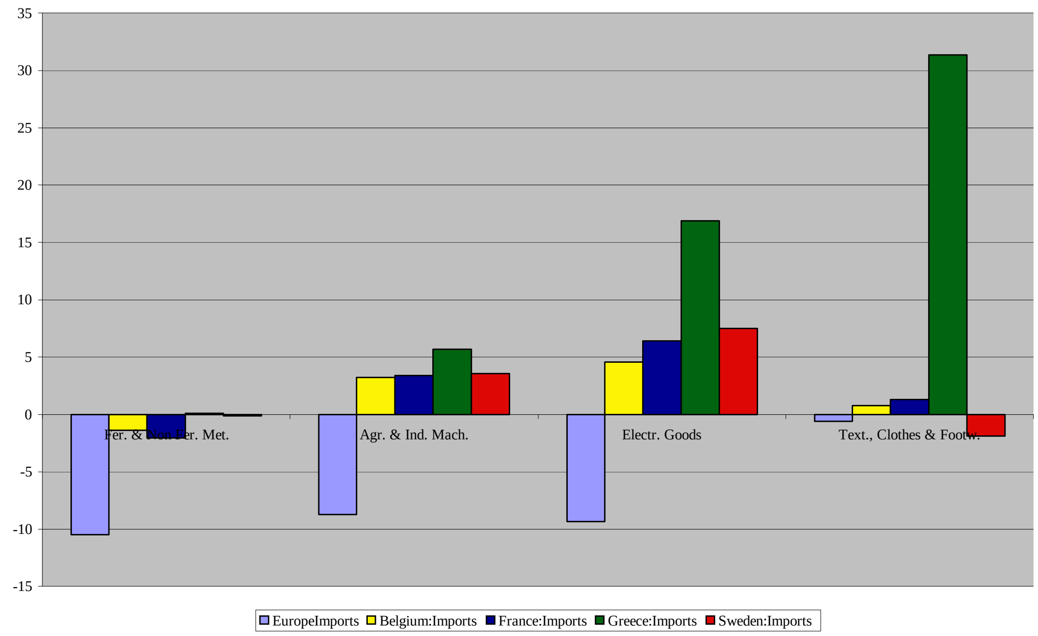
* As a % compared to the trend-based count.

Graph 18. External trade in 2030*

a. Exports[1]



b. Imports[2]



[1] National exports include exports within and outside Europe, while European exports include only those sent to countries outside the European Union.
[2] National imports include exports within and outside Europe, while European imports include only those sent from countries outside the European Union.
* As a % compared to the trend-based count.

3.3. What can we learn from the other variant-based exercises?

To provide a framework for the results of our benchmark scenario, we use a set of assumptions in the Nemesis model concerning the mechanisms of the model or R&D policy itself.

3.3.1. Sensitivity variant

→ **Sensitivity of results with regard to elasticity β**

In each economic sector, the value of the elasticity of GDP to the stock of knowledge and its development between 2002 and 2030 condition the repercussions of a reinforcement of the R&D effort on production, productivity gains, improved product quality and job creation. We therefore consider two other scenarios for this parameter of the model.

Table 6. Results of variants on the elasticity of GDP in the stock of knowledge

		Europe	Greece	Belgium	France	Sweden
$V_{0.0}$	GDP[1]	12.1	49.8	7.5	7.1	3.7
	Total Employment[2]	10 007	781	155	949	62
β = 0.124 in 2030	Employment in Research[2]	3 140	199	59	346	9
	Budget Balance[3] 2010	0.13	0.26	0.13	0.07	0.2
$V_{1.0}$	GDP[1]	16.3	79.8	9.6	9.8	5.4
	Total Employment[2]	14 222	1239	210	1 491	95
β = 0.141 in 2030	Employment in Research[2]	3 433	242	63	379	11
	Budget Balance[3] 2010	0	0.04	0.1	0	0.15
$V_{2.0}$	GDP[1]	10.9	34.7	6.6	6.1	2.4
	Total Employment[2]	5 720	480	105	485	35
β = 0.10	Employment in Research[2]	3 044	178	57	339	9
	Budget Balance[3] 2010	0.41	1.28	0.2	0.19	0.24

[1] as a difference from the trend-based count 2030, as a %.
[2] as a difference from the trend-based count, in thousands.
[3] in GDP points

- *Change to the law of evolution of elasticity*

The variant $V_{1.0}$ is achieved with the same assumptions as in variant $V_{0.0}$, except that the law of evolution of β is modified.[60] Here, it gives less weight to the fixed part of β. In this case, the results are slightly more favourable, as the growth of GDP is 16.3 % for Europe (with 1.8 % in 2010, 4.8 % in 2015 and 8.5 % in 2020) and varies between 5.4 % for Sweden and 79.8 % for Greece. Results for employment are also better, with 14.2 million extra jobs in Europe (2.2 in 2010, 3.7 in 2015 and 6.7 in 2020). There are three reasons for this:

— In variant $V_{0.0}$, β varies by 0.075 in 2002 to 0.124 in 2030, while in $V_{1.0}$, β varies by 0.075 to 0.141, which means that the influence of R&D on production is greater over the long term in variant $V_{1.0}$ than in variant $V_{0.0.}$

— In $V_{1.0}$, as the weight given to R&D intensity in determining β is greater, sector elasticities are proportionally greater and increase even more in those sectors that carry out a significant proportion of R&D. The R&D-intensive sectors thus gain more in competitiveness in variant $V_{1.0}$ than in $V_{0.0}$.

— Lastly, the GDP difference between the two variants $V_{0.0}$ and $V_{1.0}$, coupled with the fact that the increase in labour productivity in labour-rich sectors is relatively higher in $V_{1.0}$ explains the better results for employment in this variant.

- *Maintaining constant, identical elasticity in all sectors and countries*

In scenario $V_{2.0}$, we assume β to be identical in all sectors in order to test the sensitivity of results against the assumption of β's dependence on R&D effort. The average value of β in

[60] We modify coefficients a and a' and β is deduced *ex post facto*. β can only be adjusted by trial and error.

this variant $V_{2.0}$ is assumed to be equal to 0.1, which brings us close to the average values in $V_{0.0}$. We observe that this assumption more unfavourable to growth and employment due, first of all, to the low productivity of R&D in R&D-intensive sectors and, secondly, to greater labour productivity in labour-rich sectors, which tends to relatively reduce employment. This increase in GDP is therefore no more than 10.9 % in Europe (1.8 % in 2010, 4.2 % in 2015 and 6.8 % in 2020), varying between 2.4 % in Sweden and 34.7 % in Greece. Job creation is nearly half that obtained in benchmark scenario $V_{0.0}$.

→ **Variants concerning the distribution of added value**

In benchmark scenario $V_{0.0}$, one third of productivity improvements are passed on to employees and the rest is retained by companies. Salaries also rise in line with the Phillips effect, in which actual salary depends on tensions in the labour market, so that actual salary rises by more than 33 % in a period of reduced unemployment. Two other variants concerning the distribution of added value are examined: one, known as $V_{4.0}$, in which salaries do not gain any benefit from productivity gains and do not therefore depend on the Phillips effect; the other, known as $V_{5.0}$, in which all labour productivity gains are redistributed to employees.

Table 7: Results of variants on the distribution of added value

		Europe	Greece	Belgium	France	Sweden
$V_{0.0}$ **Benchmark scenario**	GDP[1]	12.1	49.8	7.5	7.1	3.7
	Total Employment[2]	10 007	781	155	949	62
	Employment in Research[2]	3 140	199	59	346	9
	Budget Balance[3] 2010	0.13	0.26	0.13	0.07	0.2
$V_{4.0}$ **0 % to Employees**	GDP[1]	12.7	49.8	7.8	7.3	3.5
	Total Employment[2]	11 077	818	185	1 035	63
	Employment in Research[2]	3 174	199	60	338	9
	Budget Balance[3] 2010	0	-0.04	-0.02	-0.03	0.11
$V_{5.0}$ **100 % to Employees**	GDP[1]	11.1	49.7	6.8	6.5	4.1
	Total Employment[2]	7 971	709	94	791	63
	Employment in Research[2]	3 073	199	58	342	9
	Budget Balance[3] 2010	0.38	0.93	0.47	0.30	0.4

[1] as a difference from the trend-based count 2030, as a %.
[2] as a difference from the trend-based count, in thousands.
[3] as a percentage of GDP

From an examination of these variants (Table 7), it appears that the best results in terms of GDP and, above all, jobs are obtained with the most moderate salary approach. Though differences between scenarios are slight for GDP, they are significant for employment. These results are explained by the greatest competitiveness in Europe in scenario $V_{4.0}$ and the most favourable substitution for employment where the labour cost is lower. In fact, the closeness of effects in terms of GDP conceals growths that are quite different in content. In the scenario with a moderate salary approach ($V_{4.0}$) growth is led more by the exporting sectors, such as equipment goods. However, no assumption has been made concerning the use of the extra gross operating surplus. Companies may in fact use this distortion of the distribution of added value in two ways: firstly, in further price reductions to increase their competitiveness, secondly, in investment[61]. In the scenario with the strong increase in salaries ($V_{5.0}$), growth is explained more by household consumption.

3.3.2. Variants concerning R&D policy

The variants for implementing the policy for increasing R&D effort are understood on the assumption of median mechanisms of the model and therefore named $V_{0,i}$.

[61] However, the Nemesis model does not include the influence of profitability on company investment.

→ Public financing of R&D

The exercise with public financing of increased R&D ($V_{0.1}$) leads to better performance in the multiplier phase and in the phase in which supply effects develop. In fact, in 2030, the growth of GDP is 15.2 % in Europe (2.3 % in 2010, 5.4 % in 2015 and 8.8 % in 2020) compared to 12.1 % in the benchmark scenario $V_{0.0}$ (1.7 % in 2010, 4.2 % in 2015 and 7 % in 2020) where the financing is private. If we relate the growth surplus to the *ex ante* deficit, i.e. due simply to increased expenditure linked to Government support of R&D, the multiplier is 8.1 in Europe. With public financing, all countries benefit from an increase in their GDP approximately 1.3 times higher than in the benchmark scenario.

Table 8: Results of variants in the implementation of the policy

		Europe	Greece	Belgium	France	Sweden
$V_{0.0}$ Benchmark scenario	GDP[1]	12.1	49.8	7.5	7.1	3.7
	Total Employment[2]	10 007	781	155	949	62
	Employment in Research[2]	3 140	199	59	346	9
	Budget Balance[3] 2010	0.13	0.26	0.13	0.07	0.2
$V_{0.1}$ Public-sector finance	GDP[1]	15.2	65.3	9.7	8.8	4.5
	Total Employment[2]	13 867	1139	220	1 321	92
	Employment in Research[2]	3 273	221	60	359	10
	Budget Balance[3] 2010	-0.81	-2.55	-0.64	-0.57	-0.08
$V_{0.4}$ public-sector orders	GDP[1]	15.8	58.7	9.8	9.5	4.6
	Total Employment[2]	17 104	1021	263	1 867	159
	Employment in Research[2]	3 298	212	60	364	12
	Budget Balance[3] 2010	-1.19	-2.01	-0.96	-1.07	-0.54

[1] as a difference from the trend-based count 2030, as a %.
[2] as a difference from the trend-based count, in thousands.
[3] in GDP points

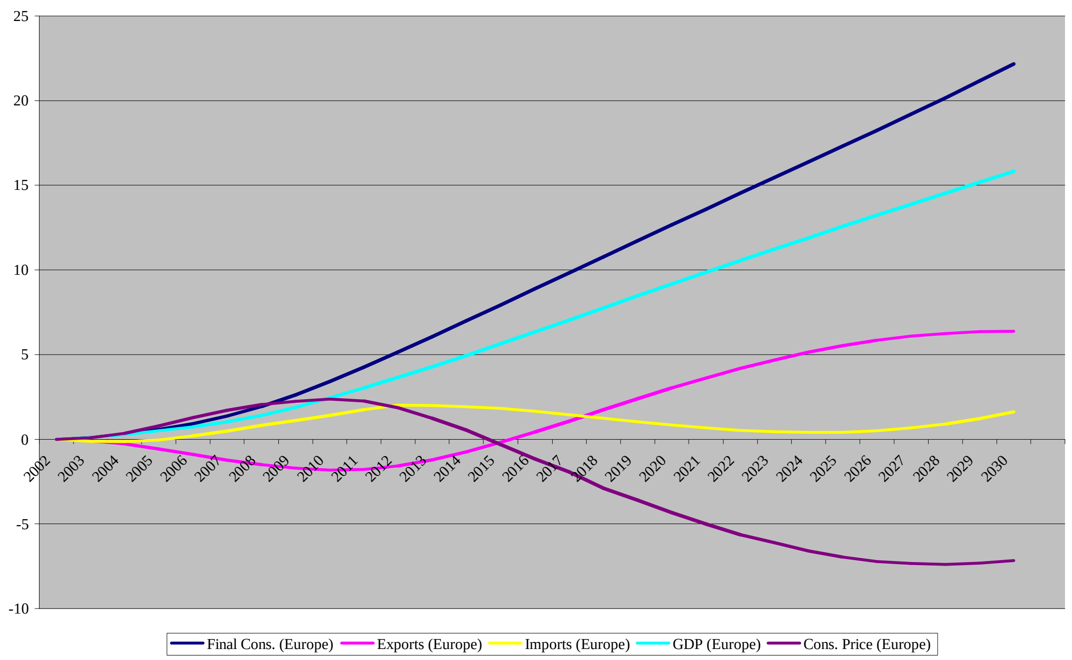
This is explained by the increase in Government deficit, which helps to avoid inflationary tensions due to the financing of R&D through company price increases in $V_{0.0}$. Companies' losses of competitiveness are thus limited in the first period. Growth in imports and the relative fall in exports are thus reduced in this scenario. This advantage in terms of competitiveness is still found in the long term, which, in 2030, explains the stronger growth of GDP. It also leads to a higher number of job creations: 13.9 million extra jobs are created in Europe (2.4 in 2010, 4.2 in 2015 and 6.9 in 2020): strong growth in Greece generates 1.1 million extra jobs, and French growth, though much weaker, also leads to more jobs, with 1.3 million jobs being created in 2030. On the other hand, due to the limited size of their working population and the slightness of the impact, Belgium, with 220,000 extra jobs, and Sweden, with only 92,000, contribute only 2 % to the number of jobs created in Europe.

It thus appears that this type of public-sector boost, directed at investment in R&D, is not unfavourable to countries' competitiveness, even over a 30-year period. The inflationary tensions engendered by extra demand are reduced by productivity gains from investment in R&D. Nevertheless, we should not exaggerate the influence of this result. In fact, as the model is not financially integrated, there is no public deficit return on interest rates and financial and economic performance in general. However, we can see that government finances remain in surplus (from 2017 for Europe). In 2030 this surplus is 2 % of GDP in Europe. Though these results are optimistic, they encourage us to reflect on the particular character of deficits linked to R&D due to their limited duration and even the extra GDP and balance of government finances that they engender in the long term.

→ Markets and public-sector orders

In variant $V_{0.4}$, increased R&D effort comes partly from orders placed with R&D-intensive sectors (chemicals, office machines, electrical goods and transport equipment). The orders represent 2.5 % of European GDP in 2010. This is equivalent in 2010 to a growth in production of 8.9 % for chemicals, 12.1 % for office machines, 18 % for electrical goods and 9.4 % for transport equipment. These figures are very high. Despite this, growth in R&D is not enough to achieve the Barcelona objectives and extra effort has to be added by all companies. In fact, public-sector orders sent to intensive sectors increase R&D intensity by one third of the effort needed in 2010. The remaining two-thirds are implemented in the same way as in variant $V_{0.0}$.

Graph 19. Macro-economic impacts of public-sector orders*



* As a % compared to the trend-based count.

In terms of both GDP and jobs, the results of variant $V_{0.4}$ are more favourable than those obtained with scenario $V_{0.0}$ throughout the period. European GDP increases by 2.5 % in 2010, 5.7 % in 2015, 9.2 % in 2020 and 15.8 % in 2030, while employment increases by 3.5 million in 2010, 5.9 million in 2015, 9.1 % in 2020 and 17.1 million in 2030. This is due to the knock-on effect created by public-sector orders financed by government deficit. However, during the first phase, the European economy is less competitive than in variant $V_{0.0}$. In fact, extra demand leads to inflationary tensions that are not balanced by the effects of R&D on productivity. Strong job creation in the R&D-intensive sectors encourage both consumption and an increase in salaries *via* the Phillips effect, which in return sustains demand. For example, in 2010, actual salaries go up by 2.7 % in $V_{0.4}$ in 2010 and by 1.4 % in $V_{0.0}$. During the second phase, after 2010, price growth is limited by the beneficial effects of R&D. But, in comparison with the central scenario, the European GDP deflator is two times less reduced in 2030. The benefits of the policy in terms of competitiveness are therefore lessened by budget reflation. It thus appears that, here, growth is led more by demand. The beneficial effects of R&D are not enough to totally cancel out the inflationary tensions of the Keynesian reflationary policy, but they do help to delay the negative effects.

In this scenario, the concentration of R&D effort on technologically advanced sectors thus procures three types of advantages in comparison with the benchmark scenario $V_{0.0}$:

- R&D productivity increases more sharply;
- The role of technological spillovers is increased;
- productivity gains are limited in labour-intensive sectors, which is very favourable to employment growth.

Conclusion

The European policy of increasing R&D effort leads the economy into a two-phase change. Between 2002 and 2010, European Union countries benefit from an increase in R&D expenditure, as a result of the Keynesian multiplier, but the reflation extends the external deficit with non-European countries. This R&D maturation phase is followed by a period of deployment of the effects of innovation, which leads to sustained demand and improved competitiveness vis-à-vis countries outside the European Union. Within the Union, the relative competitiveness of the most R&D-intensive countries, such as France and Sweden, is improved at first, as the extra research effort is less than for most of their European partners. However, during the second period, the less R&D-intensive countries in 2002, such as Greece, have caught up. For these countries, this leads to significantly greater productivity gains and product quality than Germany, France, Belgium and the Northern European countries. The latter lose their relative competitiveness within Europe after 2010. However, gains in competitiveness vis-à-vis countries outside Europe are such that all countries are winners in terms of growth and employment.

According to the scenario under consideration, European GDP should grow by between 10.9 % and 15.8 % in 2030[62]. Surplus growth would therefore be around 0.5 % per year on average in Europe. But this result, which particularly takes into account "volume" effects, underestimates "qualitative" growth, which includes improvements in product quality in addition to these effects; in this case, Europe's extra growth could reach 0.8 % per year. Depending on its initial research intensity, a country within the Union will benefit from an improved annual growth rate of 0.2 %, as in Sweden, to 2 %, as in Greece, and of course much more if we also include the quality effect. Of the ten million jobs created in Europe, three million are in the field of research. The greater the amount of extra research, the greater the repercussions of the R&D policy on job creation in every country in terms of the proportion of active population in the country. Greece thus benefits from 8 % of new jobs in Europe, while France creates 10 % and Sweden 0.6 %.

Growth in GDP and employment is higher where R&D is financed by the public sector, but the influence of this result is limited as the model does not take into account the negative effects of government deficits on interest rates and the performance of economic groups.

Assumptions involving a moderate salary approach with regard to the distribution of productivity gains are favourable to GDP and employment. This is due to greater gains in competitiveness and a substitution effect favourable to labour.

Sector-based results are contrasting. They mainly depend on the R&D intensity of each sector. The equipment goods and chemicals sectors are thus favoured due to their high R&D content and the size of their exports. The consumer goods sectors are led by internal demand. On the other hand, the intermediate goods and equipment goods sectors, which are not very R&D-intensive, suffer from the productivity gains in other sectors.

Public-sector orders have a major role to play in leading Europe towards its objective of becoming "the most competitive and dynamic knowledge-based economy in the world". Though they engender an initial increase in government and external deficits, they help to achieve strong growth accompanied by significant job creation due to high multipliers. In addition to the reflationary effect due to the increase in public expenditure, the economy benefits from a concentration of the extra R&D effort on high-technology sectors. In fact, these sectors benefit from higher R&D productivity and, at the same time, are major purveyors of knowledge spillovers and surplus spillovers. In addition, a lesser increase in productivity in labour-intensive sectors, which is the counterpart to this concentration on sectors that are already very R&D-intensive, leads to strong growth in employment.

[62] Between 1.8 and 2.5 % in 2010, 4.2 and 5.7 % in 2015 and 6.8 and 9.2 % in 2020.

Lastly, we should emphasise certain limitations to the exercise due to the assumptions that we have adopted (no specific reaction from countries outside Europe), the mechanisms in the model (fixed exchange rate) and the size of the impact for a country like Greece, where the results should be interpreted with a great deal of caution.

Not all the consequences of the 3 % policy for research have been discussed in this report, which has concentrated on changes in growth, competitiveness and employment in Europe; the environmental variables in the Nemesis model show, for example, that, if the policy was implemented under certain conditions, the 3% objective could be achieved without increasing $C0_2$ emissions (Cf. appendix 4 *below*) and even help to reduce greenhouse gas emissions in the European Union; this demonstrates the more environmentally-friendly nature of a knowledge-based economy.

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Appendix 1: A set of complementary variants

To provide a more precise framework for the macro-economic consequences of increasing the R&D effort in Europe, two extra scenarios were simulated using the Nemesis model.

→ We propose an alternative assumption concerning the portion taken up by private companies in the R&D effort. In the benchmark scenario, in line with the Barcelona objective, a third of research of public origin and the rest is carried out by the private sector in 2010. In scenario $V_{0.2}$, the whole increase in R&D effort comes from the private sector, while the intensity of public R&D remains constant. This variant has been made in order to compare the respective economic performances of the public and private research systems, which depend to a large extent on the spillovers from the public sector into the private sector.

→ In the benchmark scenario, we assume that the policies that have been introduced imply the total convergence of research effort for a very distant date, 2050, by which all countries should have achieved an intensity of 4 %. In scenario $V_{0.3}$, the initial differences (in 2002) in R&D intensity are maintained, which will lead to only a relative convergence of R&D effort in Europe in 2050.

The following Table compares the key results obtained in the different scenarios.

Table 9: Summary of the results in 2030 *(except budget balance in 2010)*

	Productivity gains: 0 % to Employees	Productivity gains: 100 % to Employees	Productivity gains: 33 % to Employees	β = 0.141 in 2030	β = 0.10 in 2030
Public-sector Finance for Research			**$V_{0.1}$** GDP 15.2 Employment 13 867 Res. Employment 3 273 Budget Balance -0.81		
Private-sector Finance for Research	**$V_{4.0}$** GDP 12.7 Employment 11 077 Res. Employment 3 174 Budget Balance 0	**$V_{5.0}$** GDP 11.1 Employment 7 971 Res. Employment 3 073 Budget Balance 0.38	**$V_{0.0}$** GDP 12.1 Employment 10 007 Res. Employment 3 140 Budget Balance 0.13	**$V_{1.0}$** GDP 16.3 Employment 14 222 Res. Employment 3 433 Budget Balance 0	**$V_{2.0}$** GDP 10.9 Employmen 5 720 Res. Employment 3 044 Budget Balance 0.41
Public-sector orders			**$V_{0.4}$** GDP 15.8 Employment 17 104 Res. Employment 3 298 Budget Balance -1.9		
100 % Private Research			**$V_{0.2}$** GDP 12.9 Employment 8 315 Res. Employment 2 957 Budget Balance 0.32		
Relative Convergence			**$V_{0.3}$** GDP 13.7 Employment 11 180 Res. Employment 3 298 Budget Balance -0.02		

Appendix 2: Results by country in the EU-15+

This appendix presents the results in terms of GDP, employment, research employment and government budget balance, for each country in the European Union plus Norway (EU-15+), and all the scenarios studied.

Table 10: The results of scenario $V_{0.0}$: benchmark scenario, β = 0.124 in 2030*

	Total Employment		Research Employment		GDP		Budget Balance	
	2010	*2030*	*2010*	*2030*	*2010*	*2030*	*2010*	*2030*
Austria	36	145	29	52	1.06	9.01	0	1.15
Belgium	41	155	34	59	1.17	7.52	0.13	0.70
Denmark	24	64	22	39	0.96	8.08	-0.07	0.71
Germany	366	1722	324	441	1.06	7.62	0.04	0.95
Finland	17	63	16	35	0.88	5.85	0.08	-0.42
France	303	949	208	345	1.18	7.06	0.07	0.97
Greece	102	781	80	199	6.26	49.84	0.26	11.45
Ireland	55	231	55	133	1.74	15.81	0.11	1.00
Italy	368	1728	332	627	2.98	19.82	0.59	5.44
Netherlands	75	384	58	124	0.95	8.05	0	1.05
Norway	39	157	29	53	1.56	12.71	0.62	3.65
Portugal	39	221	57	119	4.37	24.71	0.45	5.01
Spain	205	1008	219	402	3.19	22.62	0.18	6.28
Sweden	13	62	9	9	0.79	3.67	0.19	-0.28
U.K.	400	2335	250	502	1.51	12.75	-0.03	3.16
Europe	**2084**	**10007**	**1634**	**3140**	**1.70**	**12.15**	**0.13**	**2.33**

*: Employment and Research Employment in thousands, GDP in %, Budget Balance in GDP points.

Table 11: The results of scenario $V_{1.0}$: β = 0.141 in 2030*

	Total Employment		Research Employment		GDP		Budget Balance	
	2010	*2030*	*2010*	*2030*	*2010*	*2030*	*2010*	*2030*
Austria	37	206	29	54	1.15	11.45	-0.10	0.86
Belgium	42	210	34	63	1.26	9.65	-0.10	0.96
Denmark	24	100	23	41	1.17	11.89	-0.15	0.76
Germany	374	2689	235	492	1.13	10.93	-0.02	0.84
Finland	17	96	16	38	0.96	7.74	0.04	-0.92
France	313	1491	208	379	1.24	9.79	0	0.78
Greece	103	1239	80	242	7.12	79.81	0.04	17.61
Ireland	55	357	55	145	2.07	24.57	0.10	1.49
Italy	404	2488	331	652	2.94	23.44	0.37	5.81
Netherlands	79	556	58	135	0.98	10.25	-0.09	0.50
Norway	40	206	29	57	1.71	16.84	0.54	4.04
Portugal	57	463	57	128	4.36	33.48	-0.14	4.87
Spain	224	1402	220	423	3.18	27.34	-0.05	7.07
Sweden	13	95	10	11	0.62	5.43	0.15	-0.36
U.K.	416	3623	251	573	1.69	18.34	-0.14	3.43
Europe	**2197**	**15222**	**1637**	**3433**	**1.78**	**16.28**	**0**	**2.78**

*: Employment and Research Employment in thousands, GDP in %, Budget Balance in GDP points.

Table 12: The results of scenario $V_{2.0}$: $\beta = 0.1$*

	Total Employment		Research Employment		GDP		Budget Balance	
	2010	*2030*	*2010*	*2030*	*2010*	*2030*	*2010*	*2030*
Austria	30	91	29	52	1.04	8.54	0.21	1.45
Belgium	37	105	34	57	1.11	6.64	0.20	-0.12
Denmark	23	22	22	37	0.79	5.57	0.08	0.48
Germany	327	1005	234	424	1.01	6.42	0.16	0.85
Finland	15	36	16	34	0.80	5.29	0.14	-0.55
France	267	485	208	340	1.13	6.14	0.19	0.91
Greece	87	480	80	178	6.46	34.68	1.28	10.40
Ireland	51	145	55	127	1.65	11.50	0.30	1.14
Italy	278	966	334	628	3.44	20	1.22	6.65
Netherlands	64	249	58	120	0.96	7.90	0.20	1.76
Norway	35	111	29	51	1.53	10.52	0.83	3.31
Portugal	-3	-43	57	116	5.11	21.73	1.08	8.43
Spain	141	631	221	405	3.69	23.14	0.89	7.60
Sweden	11	35	10	9	0.65	2.36	0.24	-0.79
U.K.	349	1403	249	467	1.44	10.44	0.22	3.73
Europe	**1714**	**5720**	**1637**	**3044**	**1.77**	**10.89**	**0.41**	**2.90**

*: Employment and Research Employment in thousands, GDP in %, Budget Balance in GDP points.

Table 13: The results of scenario $V_{4.0}$: 0 % to Employees*

	Total Employment		Research Employment		GDP		Budget Balance	
	2010	*2030*	*2010*	*2030*	*2010*	*2030*	*2010*	*2030*
Austria	39	186	29	53	1.11	9.96	-0.1	0.61
Belgium	45	185	34	60	1.17	7.84	-0.02	-0.10
Denmark	26	85	22	39	1.01	8.72	-0.18	0.09
Germany	377	1878	234	446	1.02	7.98	-0.05	0.034
Finland	18	72	16	35	0.83	5.99	-0.02	-1.07
France	315	1035	208	348	1.17	7.32	-0.03	0.45
Greece	104	818	80	199	6.08	49.83	-0.04	9.60
Ireland	57	274	55	135	1.84	17.20	-0.03	0.18
Italy	384	1867	332	631	2.99	20.45	0.45	4.66
Netherlands	82	451	58	127	0.99	8.68	-0.11	0.48
Norway	39	161	29	52	1.43	12.39	0.46	2.77
Portugal	43	265	57	120	4.37	25.38	0.23	3.84
Spain	213	1117	220	407	3.20	23.54	0.03	5.58
Sweden	14	63	10	9	0.72	3.48	0.11	-0.76
U.K.	428	2620	250	513	1.53	13.56	-0.15	2.68
Europe	**2185**	**11077**	**1633**	**3174**	**1.69**	**12.65**	**-0.01**	**1.88**

*: Employment and Research Employment in thousands, GDP in %, Budget Balance in GDP points.

Table 14: The results of scenario $V_{5.0}$: 100 % to Employees*

	Total Employment		Research Employment		GDP		Budget Balance	
	2010	*2030*	*2010*	*2030*	*2010*	*2030*	*2010*	*2030*
Austria	29	64	29	51	0.92	7.11	0.24	2.28
Belgium	32	94	34	58	1.14	6.82	0.47	2.38
Denmark	20	24	22	38	0.85	6.78	0.18	2.01
Germany	330	1447	235	430	1.11	6.97	0.27	2.23
Finland	15	48	16	35	0.95	5.60	0.32	1.00
France	270	791	208	343	1.18	6.53	0.30	2.09
Greece	95	709	80	199	6.57	49.74	0.93	15.52
Ireland	48	146	55	129	1.47	12.86	0.45	2.75
Italy	326	1457	331	617	2.90	18.52	0.89	7.10
Netherlands	59	256	58	119	0.81	6.78	0.26	2.26
Norway	37	148	29	53	1.83	13.44	1.01	5.70
Portugal	30	134	57	117	4.30	23.23	0.93	7.46
Spain	184	800	220	395	3.09	20.78	0.50	7.79
Sweden	10	63	10	9	0.92	4.10	0.40	0.78
U.K.	325	1788	249	480	1.42	11.12	0.21	4.21
Europe	**1808**	**7971**	**1633**	**3073**	**1.67**	**11.14**	**0.38**	**3.92**

*: Employment and Research Employment in thousands, GDP in %, Budget Balance in GDP points.

Table 15: The results of scenario $V_{0.1}$: public-sector financing*

	Total Employment		Research Employment		GDP		Budget Balance	
	2010	*2030*	*2010*	*2030*	*2010*	*2030*	*2010*	*2030*
Austria	44	214	30	54	1.66	11.39	-0.79	0.77
Belgium	45	220	35	60	1.73	9.71	-0.64	0.23
Denmark	29	97	23	40	1.42	9.87	-0.80	0.13
Germany	346	1929	237	446	1.32	8.82	-0.53	0.46
Finland	24	107	16	37	1.36	7.98	-0.38	-0.57
France	333	1321	210	359	1.56	8.80	-0.57	0.68
Greece	124	1139	82	221	8.94	65.20	-2.55	8.71
Ireland	82	465	56	145	3.68	24.32	-1.05	0.76
Italy	403	2423	335	662	3.72	24.82	-0.69	4.86
Netherlands	85	499	59	123	1.42	9.80	-0.77	0.29
Norway	38	182	29	55	2.25	15.69	-0.22	3.16
Portugal	67	465	58	128	6.08	32.98	-1.74	2.13
Spain	291	1612	224	428	4.39	28.61	-1.39	5.36
Sweden	24	92	10	10	1.04	4.54	-0.08	-0.24
U.K.	430	3102	253	503	2.11	15.62	-1.17	2.41
Europe	**2365**	**13867**	**1657**	**3273**	**2.29**	**15.20**	**-0.81**	**1.97**

*: Employment and Research Employment in thousands, GDP in %, Budget Balance in GDP points.

Table 16: The results of scenario $V_{0.4:}$ public-sector orders*

	Total Employment		Research Employment		GDP		Budget Balance	
	2010	*2030*	*2010*	*2030*	*2010*	*2030*	*2010*	*2030*
Austria	66	225	29	52	0.99	9.05	-1.08	1.66
Belgium	65	263	35	61	1.58	9.84	-0.96	1.63
Denmark	37	122	22	39	0.58	8.64	-1.30	0.78
Germany	651	2939	242	460	1.99	10.30	-1.04	1.52
Finland	43	163	16	36	1.19	7.34	-0.61	0.68
France	531	1867	212	364	1.83	9.48	-1.07	1.41
Greece	111	1021	80	212	6.85	58.67	-2.01	11.25
Ireland	100	523	58	148	5.39	26.66	-1.84	1.90
Italy	501	2782	334	664	3.41	25.11	-1.15	5.87
Netherlands	136	634	59	121	1.27	8.41	-0.87	2.14
Norway	47	221	30	57	2.75	17.54	-0.86	4.22
Portugal	86	532	58	128	5.92	33.41	-1.72	3.91
Spain	388	1937	223	430	4.20	28.95	-1.54	6.69
Sweden	47	159	10	12	0.96	4.64	-0.54	0.21
U.K.	639	3715	256	515	2.57	17.25	-1.42	3.48
Europe	**2867**	**17105**	**1622**	**3298**	**2.47**	**15.81**	**-1.19**	**3.05**

*: Employment and Research Employment in thousands, GDP in %, Budget Balance in GDP points.

Appendix 3: The results for Europe in 5-year periods

This appendix sets out the macro-economic results for the different scenarios for the EU-15+ and years 2005, 2010, 2015, 2020, 2025 and 2030.

Table 17: The results of scenario $V_{0.0}$: benchmark scenario, β = 0.124 in 2030*

Macro-economic results for Europe *						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Demand.						
- Final Consumption	0.42	2.44	5.69	9.08	12.30	15.53
- Public Consumption	0.21	0.57	0.60	0.63	0.67	0.73
- Total Investment	0.54	1.83	2.76	3.87	5.19	6.87
- *Firms' Investment*	0.38	1.42	2.13	3.03	4.25	5.88
- Intra European Trade	0.22	1.31	3.08	5.13	7.17	9.30
- Extra European Imports	0.51	1.74	0.81	-1.21	-2.81	-3.22
- Extra European Exports	-0.21	-0.20	2.58	6.92	10.93	13.72
- Gross Domestic Product	0.32	1.70	4.17	6.97	9.65	12.14
- Corrected GDP by Efficiency Indicator	0.43	3.81	9.33	15.00	20.06	24.62
Employment.						
- Total Employment**	734	2084	3089	4975	7306	10007
- Employment in Research**	551	1633	2034	2407	2755	3140
Research and Productivity.						
- Research and Development	24.48	67.30	82.97	96.77	108.12	122.97
- *private sector*	28.83	80.07	101.22	119.42	133.50	153.16
- Research Intensity***	2.29	3.00	3.12	3.25	3.38	3.51
- *private sector****	1.42	1.92	2.00	2.11	2.23	2.33
- Total Factor Productivity	0.18	0.80	1.92	3.11	4.14	5.00
- Quality Indicator	0.11	2.08	4.96	7.50	9.50	11.12
- Knowledge Indicator	1.14	21.94	59.25	96.72	127.56	152.75
Energy Consumption.						
- *Firms' Final Energy Demand*	0.22	0.45	0.40	0.55	0.90	1.60

*: as a % difference from the benchmark scenario

**: as a difference from the benchmark scenario (thousands)

***: in GDP points

Table 18: The results of scenario $V_{1.0}$: β = 0.141 in 2030*

Macro-economic results for Europe *						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Demand.						
- Final Consumption	0.42	2.52	6.37	10.84	15.57	20.78
- Public Consumption	0.21	0.57	0.61	0.64	0.68	0.75
- Total Investment	0.54	1.92	3.31	5.29	7.79	10.96
- *Firms' Investment*	0.38	1.50	2.58	4.19	6.38	9.27
- Intra European Trade	0.22	1.45	3.98	7.39	11.10	15.16
- Extra European Imports	0.51	1.73	0.59	-1.45	-2.76	-2.44
- Extra European Exports	-0.21	-0.09	3.60	9.33	14.76	18.72
- Gross Domestic Product	0.32	1.78	4.81	8.53	12.37	16.28
- Corrected GDP by Efficiency Indicator	0.43	4.15	11.02	18.92	26.88	34.90
Employment.						
- Employment**	735	2187	3742	6705	10509	15222
- Employment in Research**	551	1637	2076	2512	2945	3433
Research and Productivity.						
- Research and Development	24.48	67.45	84.76	101.22	115.85	134.64
- *private sector*	28.83	80.28	104.02	126.33	145.32	170.84
- Research Intensity***	2.29	3.00	3.13	3.28	3.42	3.56
- *private sector****	1.42	1.92	2.02	2.15	2.28	2.40
- Total Factor Productivity	0.18	0.86	2.25	3.82	5.27	6.55
- Quality Indicator	0.11	2.32	5.92	9.57	12.92	16.02
- Knowledge Indicator	1.14	21.92	59.41	98.24	131.85	161.30
Energy Consumption.						
- *Firms' Final Energy Demand*	0.22	0.54	0.84	1.54	2.61	4.24

*: as a % difference from the benchmark scenario

**: as a difference from the benchmark scenario (thousands)

***: in GDP points

Table 19: The results of scenario $V_{2.0}$: β = 0.1*

Macro-economic results for Europe *						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Demand.						
- Final Consumption	0.42	2.56	5.77	8.76	11.16	13.25
- Public Consumption	0.21	0.57	0.60	0.63	0.66	0.72
- Total Investment	0.55	1.61	2.00	2.37	2.86	3.67
- *Firms' Investment*	0.39	1.20	1.31	1.45	1.84	2.62
- Intra European Trade	0.22	1.16	2.24	3.26	4.14	5.06
- Extra European Imports	0.52	1.52	-0.16	-3.11	-5.82	-7.45
- Extra European Exports	-0.21	-0.08	2.95	7.50	11.81	14.96
- Gross Domestic Product	0.32	1.77	4.22	6.78	9.00	10.89
- Corrected GDP by Efficiency Indicator	0.47	4.28	10.02	15.39	19.67	23.11
Employment.						
- Total Employment**	733	1714	2045	3035	4284	5720
- Employment in Research**	551	1637	2036	2388	2701	3044
Research and Productivity.						
- Research and Development	24.48	67.38	82.98	95.88	105.89	119.18
- *private sector*	28.83	80.16	101.18	117.93	129.98	147.35
- Research Intensity***	2.29	3.00	3.12	3.24	3.36	3.49
- *private sector****	1.42	1.92	2.00	2.10	2.21	2.30
- Total Factor Productivity	0.18	0.85	2.05	3.26	4.27	5.06
- Quality Indicator	0.15	2.47	5.57	8.06	9.79	11.02
- Knowledge Indicator	1.14	21.98	59.74	97.81	128.65	152.91
Energy Consumption.						
- *Firms' Final Energy Demand*	0.22	0.10	-0.69	-1.39	-1.93	-2.15

*: as a % difference from the benchmark scenario

**: as a difference from the benchmark scenario (thousands)

***: in GDP points

Table 20: The results of scenario V4.0: 0 % to employees*

Macro-economic results for Europe *						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Demand.						
- Final Consumption	0.40	2.30	5.43	8.77	12.00	15.27
- Public Consumption	0.21	0.57	0.60	0.63	0.67	0.73
- Total Investment	0.54	1.79	2.68	3.79	5.16	6.93
- *Firms' Investment*	0.38	1.38	2.04	2.94	4.21	5.92
- Intra European Trade	0.20	1.23	2.93	4.95	7.00	9.18
- Extra European Imports	0.45	1.37	-0.19	-2.84	-4.98	-5.82
- Extra European Exports	-0.17	0.09	3.48	8.58	13.36	16.82
- Gross Domestic Product	0.32	1.69	4.23	7.16	9.99	12.65
- Corrected GDP by Efficiency Indicator	0.43	3.80	9.40	15.22	20.49	25.28
Employment.						
- Total Employment**	750	2185	3374	5501	8093	11077
- Employment in Research**	551	1633	2038	2419	2777	3174
Research and Productivity.						
- Research and Development	24.47	67.29	83.17	97.31	109.06	124.37
- *private sector*	28.82	80.04	101.54	120.25	134.94	155.27
- Research Intensity***	2.29	3.00	3.12	3.25	3.39	3.52
- *private sector****	1.42	1.92	2.00	2.12	2.23	2.34
- Total Factor Productivity	0.17	0.77	1.90	3.15	4.25	5.18
- Quality Indicator	0.11	2.08	4.96	7.52	9.55	11.21
- Knowledge Indicator	1.14	21.94	59.28	96.98	128.25	154.01
Energy Consumption.						
- *Firms' Final Energy Demand*	0.21	0.40	0.26	0.29	0.53	1.14

*: as a % difference from the benchmark scenario

**: as a difference from the benchmark scenario (thousands)

***: in GDP points

Table 21: The results of scenario $V_{5.0}$: 100 % to employees *

Macro-economic results for Europe *						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Demand.						
- Final Consumption	0.48	2.71	6.24	9.79	13.03	16.18
- Public Consumption	0.21	0.57	0.60	0.63	0.66	0.72
- Total Investment	0.56	1.92	2.95	4.09	5.36	6.89
- *Firms' Investment*	0.39	1.49	2.31	3.24	4.41	5.90
- Intra European Trade	0.25	1.47	3.40	5.56	7.61	9.67
- Extra European Imports	0.62	2.65	3.15	2.60	2.24	2.76
- Extra European Exports	-0.30	-0.97	0.48	3.27	5.79	7.37
- Gross Domestic Product	0.33	1.67	4.00	6.57	8.95	11.14
- Corrected GDP by Efficiency Indicator	0.44	3.79	9.15	14.51	19.17	23.29
Employment						
- Total Employment**	701	1808	2415	3870	5739	7971
- Employment in Research**	552	1633	2026	2380	2708	3073
Research and Productivity.						
- Research and Development	24.49	67.27	82.67	95.64	106.17	120.18
- *private sector*	28.85	80.02	100.80	117.68	130.54	148.94
- Research Intensity***	2.29	3.00	3.12	3.24	3.37	3.50
- *private sector****	1.42	1.92	2.00	2.10	2.21	2.31
- Total Factor Productivity	0.20	0.86	1.94	3.01	3.89	4.59
- Quality Indicator	0.11	2.08	4.95	7.45	9.39	10.94
- Knowledge Indicator	1.14	21.94	59.13	96.16	126.09	150.13
Energy Consumption.						
- *Firms' Final Energy Demand*	0.23	0.52	0.70	1.16	1.80	2.69

*: as a % difference from the benchmark scenario

**: as a difference from the benchmark scenario (thousands)

***: in GDP points

Table 22: The results of scenario V0.1: public-sector finance *

Macro-economic results for Europe *						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Demand.						
- Final Consumption	0.45	2.75	6.63	10.79	14.87	19.07
- Public Consumption	0.21	0.58	0.63	0.66	0.70	0.76
- Total Investment	0.77	2.87	4.68	6.58	8.69	11.25
- Firms' Investment	0.61	2.46	4.03	5.71	7.70	10.18
- Intra European Trade	0.24	1.54	3.70	6.22	8.78	11.50
- Extra European Imports	0.45	1.67	0.80	-1.02	-2.23	-2.01
- Extra European Exports	-0.15	0.08	3.29	7.97	12.14	14.83
- Gross Domestic Product	0.46	2.29	5.36	8.77	12.05	15.20
- Corrected GDP by Efficiency Indicator	0.57	4.44	10.67	17.11	22.97	28.40
Employment.						
- Total Employment**	711	2365	4205	6919	10140	13867
- Employment in Research**	555	1657	2084	2479	2852	3273
Research and Productivity.						
- Research and Development	24.63	68.23	84.95	99.45	111.52	127.50
- private sector	29.07	81.41	104.09	123.13	138.02	159.12
- Research Intensity***	2.29	3.00	3.12	3.24	3.36	3.49
*- private sector****	1.42	1.92	2.01	2.11	2.22	2.32
- Total Factor Productivity	0.11	0.60	1.68	2.84	3.87	4.71
- Quality Indicator	0.11	2.10	5.04	7.67	9.74	11.45
- Knowledge Indicator	1.15	22.18	60.47	99.61	132.36	159.75
Energy Consumption.						
- Firms' Final Energy Demand	0.21	0.60	0.92	1.44	2.23	3.45

*: as a % difference from the benchmark scenario

**: as a difference from the benchmark scenario (thousands)

***: in GDP points

Table 23: The results of scenario $V_{0.4:}$ public-sector orders*

Macro-economic results for Europe *						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Demand.						
- Final Consumption	0.59	3.44	7.94	12.66	17.32	22.16
- Public Consumption	0.21	0.57	0.61	0.65	0.68	0.75
- Total Investment	1.02	4.01	6.56	8.97	11.53	14.51
- Firms' Investment	0.85	3.63	6.02	8.24	10.66	13.62
- Intra European Trade	1.34	5.86	10.17	14.18	17.89	21.82
- Extra European Imports	-0.02	1.42	1.83	0.85	0.44	1.63
- Extra European Exports	-0.55	-1.80	-0.17	3.04	5.53	6.38
- Gross Domestic Product	0.50	2.47	5.65	9.17	12.57	15.81
- Corrected GDP by Efficiency Indicator	0.61	4.60	10.91	17.42	23.37	28.85
Employment.						
-Total Employment**	974	3448	5867	9116	12837	17105
- Employment in Research**	556	1662	2094	2493	2872	3298
Research and Productivity.						
- Research and Development	24.71	68.57	85.50	100.23	112.60	128.88
- private sector	29.19	81.94	104.94	124.32	139.66	161.20
- Research Intensity***	2.29	3.00	3.12	3.24	3.36	3.49
*- private sector****	1.42	1.92	2.01	2.12	2.23	2.33
- Total Factor Productivity	0.36	1.13	2.00	2.99	3.88	4.61
- Quality Indicator	0.11	2.08	4.99	7.56	9.59	11.26
- Knowledge Indicator	1.12	21.48	58.12	95.40	126.45	152.30
Energy Consumption.						
- Firms' Final Energy Demand	0.46	1.78	3.12	4.53	6.11	8.12

*: as a % difference from the benchmark scenario

**: as a difference from the benchmark scenario (thousands)

***: in GDP points

Appendix 4: Evaluation of CO_2 emissions for the various exercises

Table 24 completes the comparison of the scenarios studied with the results for CO_2 emissions evaluated in 2030 by the Nemesis model.

In benchmark scenario $\mathbf{V_{0.0}}$, emissions increase by 0.58 % in 2030 for a 12.1 % growth in European GDP. Strong productivity gains help to stabilise CO_2 emissions at around their 2002 level, while in 2030 Europe records strong growth in its GDP. For countries in Southern Europe, the result is even more remarkable; in Greece, growth in GDP of nearly 50 % is accompanied by a reduction in emissions of over 6 %; results are similar for Portugal, and, to a lesser extent, for Spain and Italy, which, with Greece, are the countries most involved in strengthening their research effort.

Table 24: CO_2 emissions in 2030 (as a % difference from the benchmark count)

	$V_{0.0}$ Benchmark Scenario β = 0.124 in 2030	$V_{1.0}$ β = 0.141 in 2030	$V_{2.0}$ β = 0.10	$V_{4.0}$ 0 % to Employees	$V_{5.0}$ 100 % to Employees	$V_{0.1}$ Public Finance	$V_{0.4}$ Public Orders
Austria	1.36	3.92	-2.45	1.33	1.55	2.67	5.49
Belgium	1.40	3.80	-2.37	1.02	2.28	2.94	7.51
Denmark	-1.37	1.91	-6.68	-1.48	-1.03	-0.44	2.71
Germany	0.12	2.60	-3.66	-0.34	1.22	0.66	5.81
Finland	-1.57	-0.35	-4.49	-2.05	-0.43	-0.41	4.22
France	2.33	4.47	-0.33	-2.11	2.91	3.65	7.40
Greece	-6.26	2.43	-17.85	-7.61	-3.23	-0.60	0.70
Ireland	-3.20	-0.55	-7.91	-3.20	-3.10	1.95	5.60
Italy	-0.03	3.33	-4.97	-0.61	1.30	2.86	7.83
Netherlands	1.84	4.29	-1.12	-1.94	1.73	3.06	5.81
Norway	-1.75	0.36	-6.34	-2.77	0.70	-1.31	4.69
Portugal	-7.16	-9.10	-6.72	-7.91	-5.52	-4.26	-0.26
Spain	1.32	5.82	-5.10	1.36	1.32	4.39	8.17
Sweden	-0.72	0.02	-2.91	-1.50	1.07	-0.19	4.30
U.K.	2.94	8.17	-2.48	3.09	2.73	5.39	9.77
Europe	**0.58**	**3.90**	**-3.93**	**0.29**	**1.31**	**2.56**	**6.80**

This relative or absolute decoupling between economic growth and CO_2 emissions can be seen in all European countries; in the Nemesis model, it is the result of the reduction in unit energy consumption (number of TEP per million of volume production) in the productive sectors. The size of the decoupling is certainly undervalued, since, in the current state of the model, there is no mechanism linking innovation and gains in technical progress with the household unit energy consumption, from which CO_2 emissions follow their total level of consumption with a virtually unitary elasticity.

The decoupling between the growth of GDP and CO_2 emissions is more or less pronounced according to the scenarios being considered. It is least significant in scenario $\mathbf{V_{0.4}}$, where GDP and emissions increase respectively by 15.8 % and 6.8 % in Europe; on the other hand, in scenario $\mathbf{V_{2.0}}$, decoupling is absolute, since emissions fall by 3.9 % while European GDP grows by 10.9 %. The size of the decoupling thus shows the extent to which productivity gains are concentrated in sectors that contribute little to total emissions (scenario $\mathbf{V_{0.4}}$) or involve more those sectors such as transport, and the production of electricity and intermediate goods that contribute most to CO_2 emissions in Europe (scenario $\mathbf{V_{2.0}}$).

Following on from other research (see Fougeyrollas *and alii* (2001)) all these results reflect the more “environmentally-friendly” character of growth based on knowledge; lastly, they emphasise the environmental benefits that Europe could obtain from an objective of 3 % of GDP for research, more directed towards the development and adoption of environmental technologies than the scenarios considered in this study.