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On R&D, medium and high-tech industries and productivity: an application to the Portuguese case

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Abstract

This paper investigates the potential impact of increased R&D efforts and structural change in Portugal on labour productivity. The paper addresses Portugal's ambition, expressed in the 2005 Technological Plan. Based on existing literature on the relation between R&D expenditures, structural change and productivity, we evaluate the contribution of R&D and high-tech industries on productivity over the last 30 years. Our results confirm the importance of governement's R&D and of business R&D in the medium to high-tech sectors, as they stimulate productivity growth. However, we cannot hypothesize that productivity growth was primarily rooted on the development of medium-high technology industries.

Keywords: Manufacturing, Productivity, Structural Change, R&D, High-tech industries
JEL Classification: O30; O40

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1. Introduction

Economic competitiveness of economies may be broadly analysed on the basis of a set of indicators, that is, production performance, productivity, innovation and international trade performance. Recent data on these indicators had given rise to serious concerns over the comparative performance of Portugal (and even Europe[2]) over the last 15 years or so.

The data for Portugal reveal that after the high-growth "new-economy" years of the second half of the last decade, growth has been considerably below the average of the EU-25. By 2005, Portuguese GDP per capita amounted to just 75 percent of the EU average. By 2005 real GDP per hour worked corresponded to 68 percent of EU-25 labour productivity. Indeed, increasing productivity emerged as main economic challenge for Europe and Portugal in particular.

Conscious of the gap, and in line with the European directives, in 2005 Portugal launched the Technological Plan with the goal of fostering growth and competitiveness. The overall goal has been embedded in a set of policy guidelines that include the following axes:

1. Knowledge – To qualify the Portuguese for the knowledge society, fostering structural measures which aim at enhancing the average qualification level of the population, implementing a broad and diversified lifelong learning system and mobilizing the Portuguese for the Information Society;
2. Technology – To overcome the scientific and technological gap, reinforcing public and private scientific and technological competences and recognizing the role played by enterprises in the process of creation of qualified jobs and Research & Development (R&D) related activities;
3. Innovation – To boost Innovation, helping the productive chain to get adapted to the challenges of Globalization by means of the diffusion and development of new procedures, organizational systems, services and goods.

Within the spefific objectives and targets, it is notorious the attention diverted towards the need to increase the value added per employee and thus to reducing

[2] Motivating the Lisbon Strategy in 2000 and its 2005 refocus on the objectives of jobs and growth.

the gap with the EU-25. The increase of public and business R&D is also a priority and a specific objective of the plan. Medium and high-tech industries deserve otherwise particular enphasis in the Technological Plan. The data of the year base and of the Portuguese targets related with R&D and industrial structural change are reflected in the next table.

Table 1. Selected targets of the Portuguese Technological Plan

Indicators		Target 2010	Indicator		Year
			Portugal	EU-25	
S&T	Public spending in R&D as percentage of GDP	1%	0.6%	0.7%	2002
	Business spending in R&D as percentage of GDP	0.8%	0.3%	1..3%	2002
Competitiveness & Innovation	Employment in medium and high-tech industries as percentage of total employment	4.7%	3.1%	6.6%	2003
	Value added of medium and high-tech industries	6.2%	4.9%	15.8%	2003
	Exports of high-tech as percentage of total exports	11.4%	7.4%	17.8%	2003
	Creation of firms in medium and high-tech sectors as percentage of total nº of enterprises creation	12.5%	-	-	-

Source: Technological Plan (2006).

These aims and targets of the plan are clearly understood within a context of generalized acceptance of the nexus between innovation, structural change and productivity. It is often argued that R&D and high-tech industries drive growth processes, and that they are the sources of growth in output, employment and productivity in the knowledge economy. Following Kaloudis and Smith (2005), a broad set of hypotheses are implied in these R&D-biased explanations of growth. We highlight the following:

- Innovation accounts for a significant part of growth in modern economies;
- There should be a significiant correlation between shares of high-tech in total output and levels/growth rates of productivity and GDP.

Regarding the first hypotheses, the relation between R&D and productivity is strongly accepted in the literature. Even though, Griliches (1995) argues that the scientific and quantitative support for the relationship between the two aspects is rather limited. As for the impact of changes in industrial structure, it is widely recognized that the most technologically developed industries are more productive than the remainder (Aiginger, 2001). However, empirical evidence on the contribution of structural change within manufacturing to productivity is rather scarce and far from consensual (Kaloudis and Smith, 2005).

In what follows we explore the theoretical support for these hypotheses and test them in the Portuguese case. Because the high-tech industries, by definition, are all located within manufacturing, we focus in this paper primarily on the manufacturing sector. This study presents estimates of the contribution of R&D and structural change to productivity growth in the Portuguese Manufacturing Industry (PMI) over the period 1980-2003. It contributes to the existing literature in this field of analysis in two ways. First, the major sources of new technology are taken into account simultaneously: public R&D and business R&D in medium to high-tech sectors. Second, an attempt is made to evaluate the impact of the increasing weight of medium to high-tech industries in the manufacturing employment. The results are intended to provide insights into the following:

- The contribution of public research to productivity growth;
- The contribution of business R&D in high-tech sectors to productivity growth;
- The importance of structural transformation towards innovation intensive sectors to productivity growth.

The article is organised as follows. In the next section we provide the theoretical background to analyse the relation between R&D and productivity and then between structural change and productivity. In section 3 we discuss the data and methodology, and point to the critical aspects of Portuguese competitiveness, including a characterization of the manufacturing industry over the period 1980-2003. Subsection 3.2 presents our empirical study while section 4 derives policy implications and further research avenues.

2. Productivity, R&D and industrial structure

In this section we discuss the relationships between productivity, R&D and industrial structure. These are used to define the hypoheses to be tested in the context of the Portuguese economy.

2.1. R&D and productivity

> *"It is now well-known that both the governments of and private firms in most industrialised countries have devoted an increasing amount of resources to R&D. One of the main objectives of economic analysis is to evaluate whether the returns on this investment justify the initial expenditure. To this end, the relationship between R&D and productivity growth has been investigated at different levels of aggregation: economy, sector, industry and firm." (Aiginger, 2001)*

The relationship between R&D and productivity of a country is commonly accepted in the literature. R&D resulting in new goods, new processes and new knowledge, is generally accepted as major source of technical change. As defined by the *Frascati Manual* (OECD, 1993), R&D "comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge and the use of this stock of knowledge to devise new applications".

The relationship between R&D and innovation is a complex and a non-linear one. In order to capture the links between R&D and productivity it is necessary to take several aspects into account. First, there are different types of R&D, and the effects of R&D on productivity may work through various channels. Second, R&D is not the only source of new technology: in modern and industrial economies, other activities such as learning by doing or design are conducted in most cases on the basis of new technology coming out of R&D (*e.g.* changes in the organisation of business related to the use of information and communication technology).

However, it is also recognised that it is difficult to occur substantial advances in technology without work undertaken on a systematic basis (even serendipity tends to develop in such a context), and R&D is a good indicator of this broader phenomenon.

There is major evidence that links R&D to productivity. In modern growth economies, it is clear that the inputs of capital and labour alone cannot account for a large part of output growth (Solow, 1957). In rich empirical tradition of work on productivity growth, the total factor productivity growth has been related to the accumulation of a "knowledge stock", which is not accounted for in the measurement of the conventional stock of capital, but increases output via innovation and technological change. Economic theory (Solow, 1957;

Romer, 1990) points to technical change as the major source of productivity growth in the long run. R&D expenditures have been suggested as a way of measuring this knowledge stock, giving rise to a range of works relating R&D expenditures and productivity.

In 1979 Griliches discusses issues in assessing the contribution of R&D to productivity growth, and in 1980 he evaluated the returns of R&D expenditures in the private sector, using cross-section data from a set of companies over the period 1957-1963. The results reveal a positive correlation between the R&D expenditure and the productivity achieved by the companies, wich is given by a positive coefficient of the R&D of about 0.07. In a following work, Griliches (1995) discussed the econometric results and measurement issues in the relation between R&D and productivity. In his review, he refers the co-existance of three alternatives to analyse the relationship: case studies, econometric studies and the statistical analysis of patents. He concludes that the economic literature placed particular emphasis on econometric studies, mainly the Cobb-Douglas production functions and the CDM[3] model.

Guellec and Van Pottelsberge (2001) studied different types of R&D and analyzed their long-term effects on multifactor productivity growth. Using a sample of 16 OECD countries over the period 1980-98, they found that an increase of 1% in business R&D leads to a rise of productivity in 0.13%. The effect is larger in countries where the share of defence-related government funding is smaller. If on the other hand foreign R&D increases 1%, then productivity will rise by 0.46%. Finaly, an increase of 1% in public R&D generates an increase of 0.17% in productivity growth. The effect is larger in countries where the share of universities (as opposed to government labs) is higher and in countries where the share of defence R&D is smaler. They also concluded that the effects of R&D are higher in countries whith higher business R&D intensity.

Mairesse (2004) presents a model wich aims at quantifying the links between R&D, innovation and productivity on a panel of 4164 firms. According to his results, firms with a 20% share of innovative sales would be 15% more productive than firms with just 5% in innovative sales. In the same line, the productivity of a firm that has filed two European patents would be nearly 10% higher than that of a firm having filed a single patent.

[3] Crépon, Duguet and Mairesse.

As Mairesse, Wieser (2001) investigated the contribution of R&D to productivity performance at the micro level. Wieser's study presents a review of the literature wich demonstrates a significant impact of R&D on firm performance, but revals that the extent of the impact differs widely. On his own empirical work for a sample of 2167 large, publicly traded firms in Europe and the US, he also confirms the positive and significant contribution of R&D to productivity growth, once that his results point to a private rate of return on R&D of about 12%.

In these literature is also discussed the fact that the impact of R&D on the economy goes well beyond the direct private returns to the innovator. Hence, the economic literature contemplates the idea that expenditure in R&D can generate spillovers which assure a private return as well as a social return from this investment. Sveikauskas (2007) review of the literature on R&D and productivity growth shows that the overall rate of return to R&D is very large – about 25% for private return and 65% for social return. Most studies suggest that the private return of R&D represents only a third of the social return of R&D. Therefore, Wieser (2001) says that the incentives for the private sector invest in R&D does not reflect properly the value that the society receives from that research. This is one argument for the participation of the Government in the national R&D activities. Hence, the greater the divergence between the private and social returns of R&D, the stronger is the argument for the involvement of the Governement in these activities (Wieser, 2001).

Government and university's research has a direct effect on scientific knowledge and public missions, as it generates basic knowledge (Adams, 1990; Brooks, 1994). In many cases the effect of government's research on productivity is not measured, either because it is indirect or because its results are not integrated in existing measures of GDP (health-related research allows to improve length and quality of life, which are not taken into account in GDP measures). Basic research performed mainly by universities enhances the stock of knowledge of the society. New knowledge is not considered as an output in the current system of national accounts (contrary to physical investment and software for instance), and as such it is not included in GDP measures: hence the direct outcome of basic research is overlooked. However, basic research may open new opportunities to business research, which in turn affects productivity (Adams, 1990; Brooksm, 1994; Guellec and Van Pottelsbergh, 2001).

It is therefore not surprising that there have been very few studies of the effects of public research on productivity. Only some components of public research have been used in empirical frameworks. For instance, Adams (1990) finds that fundamental stocks of knowledge, proxied by accumulated academic scientific papers, significantly contributed to productivity growth in US manufacturing industries. Another example is provided by Poole and Bernard (1992) for military innovations in Canada, who present evidence that a defence-related stock of innovation has a negative and significant effect on the total factor productivity growth of four industries over the period 1961-85.

As seen before, the idea that innovation stimulated by R&D expenditure makes an important contribution to productivity growth has been demonstrated by several authors. However, the relation between innovative activities, innovation itself and productivity is rather complex and far from consensual. In fact, other authors suggest the existence of a negative correlation between innovation and productivity in the short run (Young, 1991; Utterback, 1994; Jovanovic and Nyarko, 1996; Christensen, 1997; Ahn, 1999; Bessen, 2002).

What is a fact is that due to the rapid progress in the number and quality of studies focused on the relation between R&D and productivity, our knowledge of these issues has seriously improved in the last two decades. Nevertheless, it remains rather modest because of the substantial difficulties in measurement and in statistical inference of causal relationships from non-experimental data (Mairesse, 2004).

2.2. Structural change and productivity

The relationship between the economic structure of a country and its productivity growth has received more attention in recent decades. Salter (1960) was the first to emphasize the importance that a structural change (modifications in the sectoral localization of labour, or possibly in the production factors in general) can have in boosting productivity.

Since then, several authors have studied the relocation of inputs in the manufacturing industry, because although there is no doubt as to the productivity gains resultant from the shift of inputs from agriculture to manufacturing (Syrquin 1988), the consequences of movements that occur inside the manufacturing industry are not very clear (Rocha, 2005).

While Salter (1960) presents significantly strong results about the benefits of structural changes in the UK economy between 1924 and 1950, more recent studies (Fagerberg, 2000; Timmer and Szirmai, 2000; Carree, 2002; Kiliçaslan and Taymaz, 2004; Singh, 2004) as we shall see below show more contained results. Some studies present a negligible or even a negative contribution of structural change to productivity growth (Singh, 2004; Kiliçaslan and Taymaz, 2004; Kaloudis and Smith, 2005).

Fagerberg (2000) focused on the impact of specialization and structural changes on productivity growth in manufacturing, using a sample of 39 countries and 24 industries over the period 1973-1990. The results reported in his study indicate that structural change still matters, but in a different way than before, because unlike what happened in the first half of the last century, the most technologically sophisticated industries decreased their shares in total employment between 1970 and 1990. In fact, the data suggest that in the sample studied by Salter, 1% higher productivity growth was associated with 1.4% higher growth in employment, while in Fagerberg's sample the relationship between productivity growth and employment is less than one half of that level. Even though, he argues that countries that have managed to increase their presence in the technologically most progressive industries like electronics (the so called electronics revolution), have experienced higher productivity growth in their manufacturing sector than other countries, due to important spill-over effects.

Similar evidences to those of Fagerberg (2000) are presented by Timmer and Szirmai (2000), but in this case on 4 Asian countries[4] and 13 subsectors of the manufacturing industry over the period 1963-1993.

Adding to Fagerberg (2000), Carree (2002) seeks to complement the analysis by estimating the impact of the employment share of technologically progressive industries using a different methodology. Fagerberg claims that an increase of the "electronics" industry in total employment will generate higher productivity growth on the manufacturing sector. However, the size of the impact, and as a consequence the extent of spill-overs, is found to be much smaller than estimated by Fagerberg.

The relationship between structural changes and productivity growth in the manufacturing sector is also investigated by Singh (2004) in his study on

[4] India, Indonesia, South Korea and Taiwan.

South Korea over the period 1970-2000. The results shows that in the seventies occured a structural bonus (productivity gains due to the structural change). However, between 1980 and 2000 the relocation of inputs in the manufacturing sector has not ensured benefits to productivity.

Kiliçaslan and Taymaz (2004) found similar results in their study on the relationship between industrial structure, productivity and competitiveness in manufacturing industry for a sample of MENA[5] and Asian[6] countries from 1965 to 1999. This study shows that the impact of the structural change in the productivity growth of the manufacturing sector is negligible for most countries, especially after the eighties. In this period, countries like Jordan and Korea present a negative correlation between the structural change and the productivity growth.

Using simple correlation analysis, Kaloudis and Smith's (2005) study of 11 OECD economies for a 23-year period (1980-2002) with data from the OECD's STAN database, concluded that structural change (share of the electronics and other high-tech industries) within manufacturing was not the direct cause of the growth process in advanced OECD economies. They did not find evidence supporting the argument that the high-tech economies are also the high growth economies. They say that different economies can follow different paths of economic growth. Countries play different roles in the differentiated international economic system with clear patterns of division of labour among the highly developed economies.

Kaloudis and Smith (2005) show that the higher the share of high-tech industries in manufacturing value added, the higher is GDP per inhabitant. Looking at income levels first, there is indeed a relationship between technological intensity and the level of income across national economies. However, they did not find any positive relationship when we compare the high-tech share in manufacturing value added with the rate of growth of GDP per inhabitant. Hence, they cannot conclude, therefore, that high-tech economies are also the high growth economies. Moreover, an additional important point is the absence of any convincing evidence for a hypothesis that low-tech economies are low growth economies. If anything, there is weak evidence in the data that low-tech economies are higher growth economies than the high-tech.

[5] Middle East and North Africa (MENA): Egypt, Iran, Jordan, Kuwait, Malta, Marocco, Tunisia and Turkey.

[6] Malaysia, Indonesia, Korea, India and Pakistan.

This evidence suggests that growth does not rest on the high-tech driven structural change.

Another fundamental question raised by Kaloudis and Smith (2005) is in which way the causality runs, since high-tech industries (in particular aerospace, ICT, and pharmaceuticals) have in practice been created via significant government support, and have invariably been initiated by substantial publicly-supported R&D infrastructures (Mowery and Rosenberg (1989), as well as Bruland and Mowery (2004) provide good overviews of this discussion). There may therefore be a pattern of causality that runs from high levels of income, to government budgetary positions, to the creation of industries – that is, some R&D-intensive industries may be a consequence of high income, not a cause of it.

From the discussion, we test the R&D-biased explanations of growth, from which it is possible to derive the following hypotheses to be tested empirically in our econometric model:

- H1) Public R&D activity has a positive impact on manufacturing productivity;
- H2) Business R&D in the High-technology and Medium-high-technology industries has a positive impact on manufacturing productivity;
- H3) An increase of the high-technology and medium-high-technology industries on the manufacturing employment has a positive impact on the manufacturing productivity.

3. Productivity, R&D and structural change: an analysis of the Portuguese manufacturing industry

The data considered in this part of the study are mainly based on three basic concepts: R&D expenditure, employment and value added. The National Statistics Institute of Portugal (*Instituto Nacional de Estatística*) and the R&D Survey from the Science and Higher Education Observatory (*Observatório da Ciência e do Ensino Superior*) are our primary data sources to estimate the econometric model over the period 1980-2003. In this study, we had to overcome an obstacle caused by a change in methodology by the National Statistics Institute of Portugal in 1990 with regard to data collection. Thus, it was necessary to extrapolate data before 1990 to ensure a single and uniform sequence of information. In the first part of the section we overview the evolution of the main variables, and test the relationship between them in the second part of the section.

3.1. Portuguese manufacturing industry in perspective: productivity, R&D and industrial structure

3.1.1 Productivity

With respect to competitiveness, let us consider what recent data tells us about the EU in general and the Portuguese economy in particular. The data for Portugal reveal that after the high-growth "new-economy" years of the second half of the last decade, growth has been considerably below the average of the EU-25. By 2005, Portuguese GDP per capita amounted to just 75 percent of the EU average.

Table 2. Real GDP growth and Real GDP per capita in PPS (EU25=100)

	1990-1995	1995-2000	2000-2005	2005	GDPpc 2005
Portugal	1,7	4,1	0,6	0,4	75
EU-25	1,7	3,0	1,8	1,8	100
USA	2,5	4,1	2,4	3,2	152

Source: European Commission (2006a). Table 2.1.

Table 3 presents labour productivity growth rates in Portugal, the EU-25 and the US[7]. The data clearly points towards a loss of competitiveness of the EU-25 as compared with the US from the mid-1990s onwards[8]. Portugal registered low labour productivity growth overall. By 2005, real GDP per hour worked

[7] The last two columns present data on productivity per worker and per hour worked in 2005. There is an on-going debate on whether this difference in the supply of working hours is due to different preferences for leisure in the EU and the US, to different taxation systems, or to differences in labour market regulations (see CPB (2006), for a recent literature review).

[8] In the period of 2000-2005, and by historical standards, TFP growth in the EU was very low. The explanations put forward to explain EU TPF performance vary between those that highlight limited innovation, undeveloped services, issues of regulation and infrastructures (European Commission, 2006a). Also, the picture is quite differentiated across EU member states. For instance, Nordic and Anglo-Saxon countries in general have TFP growth rates that are high by global standards and in some cases higher than those of US while, at the opposite end, most South European countries performed poorly.

corresponded to 68 percent of EU-25 labour productivity. Increasing productivity emerged as main economic challenge for Europe and Portugal in particular.

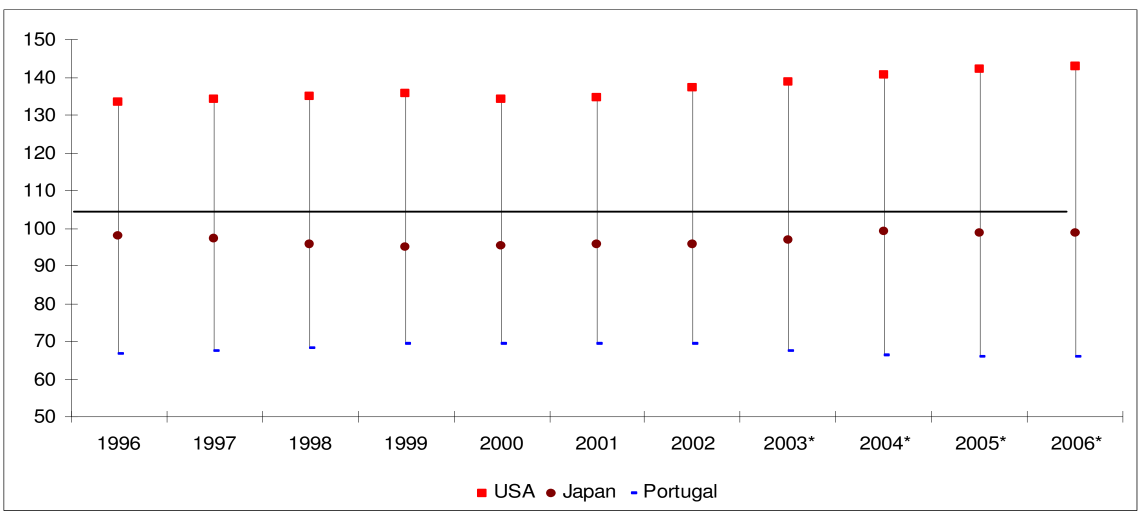
Table 3. Growth of labour productivity per person employed and 2005 levels of real GDP per person employed (ppe) and real GDP per hour worked (phw)

	Average annual labour productivity growth			Real GDP 2005		
	1990-1995	1995-2000	2000-2005	2005	GDP ppe	GDP phw
Portugal	2,3	2,2	0,3	0,3	66	68
EU-25	2,2	2,0	1,3	1,1	100	100
USA	1,3	2,0	2,2	1,8	137	129

Source: European Commission (2006a), Table 2.3.

From Graph 1, we can see that labour productivity in the EU-25 is very similar to that of Japan. On another level, the US is the most productive state. In the EU-15, the Portuguese economy reveals the lowest levels of productivity (about 65% of the EU-25 average). If we consider the 25 Member-states in that period, Portugal ranks in at 19^{th} position.

Graph 1. Labour productivity by employee in the EU-25, Portugal, USA and Japan (1996-06)

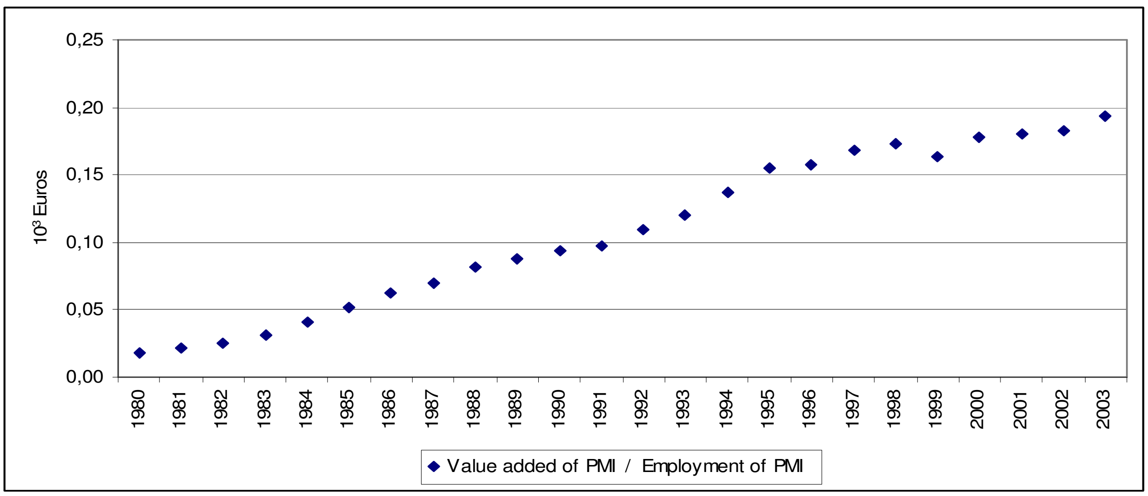


Source: Own elaboration based on "Boletim Estatístico" (2005) of "Direcção-Geral de Estudos, Estatística e Planeamento". Data from Eurostat.
* Estimative
Note: EU-25 = 100

The developments in manufacturing have an important role on the overall productivity growth. Recall that in Europe (EU-25), manufacturing accounts for about a third of employment and value-added (Eurostat, 2004). In Portugal the share of the manufacturing is similar. By 2003, the Portuguese manufacturing (section D)[9] accounted for 28 percent of the value added and employment.[10, 11]

Looking in detail at the labour productivity in the PMI over a long time period, we verify that productivity in manufacting has increased considerably, as result of both, a decline in employment and an increase in value added. The period under analysis can be divided in two cicles. The first cicle runs from 1980-1985, and the second from 1985-2003. The first period is characterized by moderate productivity growth. Aguiar and Martins (2004) explain the developments based on the international crisis on the aftermath of the Oil Shocks of 1973 and 1979, internal policies and the austerity implied by the stability plans negotiated wit the International Monetary Fund (IMF)[12].

Graph 2. Labour productivity of the Portuguese mananufacturing industry (1980-2003)



Source: Authors' own calculations based on values of "Estatísticas Industriais" (1980-1989) and "Estatísticas das Empresas" (1990-2003) from the National Statistics Institute of Portugal. Note: Value added of PMI at constant prices (consumer price index – base year 1986).

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[9] Manufacturing corresponds to section D "Secção D" and is formed by 14 subsections (industries), according to the Portuguese Classification of the Economic Activities "CAE – Rev. 2.1".

[10] Manufacturing employed about 1.153.914 employees in 1980 and 886.253 in 2003.

[11] Authors' own calculations based on values of "Inquérito Permanente ao Emprego" (1980) from the National Statistics Institute of Portugal.

[12] Stabilization Plan of 1978 -1979, and the Second Stablization Plan of 1983-1984.

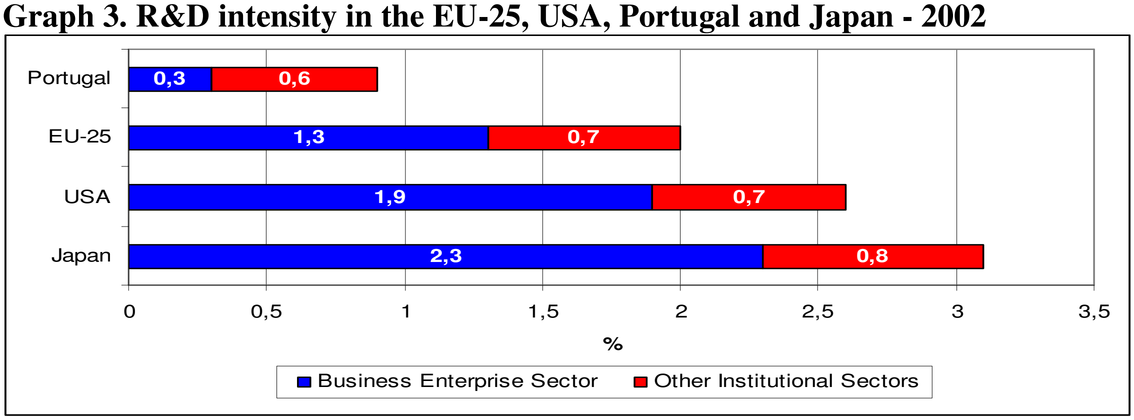
From 1985 onwards, industrial productivity accelerated, albeit in a context of 'desindustrialization'[13]. Aguiar and Martins (2004) proposed four main reasons for this evolution, namely the macroeconomic results of the stabilization plans, institutional and political stability fostering private initiative, accession to the European Economic Community (EEC) in 1986, and favourable international conditions (depreciation of the USD, decline in interest rates and in the Oil Prices).

Although labour productivity in the PMI and in the Portuguese economy in general has registered a positive evolution in the last decades, it continues to remain significantly below the European average. The above discussion highlights that Portugal has to generate faster productivity growth. The data also suggest that with a view to competitiveness it is not enough to look at capital per worker, but that innovation and an adequate business environment (factors considered by TFP) are fundamental with a view to competitiveness and growth, an issue focused by the Lisbon Agenda.

3.1.2. R&D and innovation

With regard to innovation indicators, the picture is not very favourable in spite of considerable advances. Data on R&D intensity (R&D expenditures as percentage of GDP) reveals that Portugal is well below the EU-25 average. Business expenditures in R&D in particular are relatively smaller than in other European counterparts, while public expenditures represent the largest share of total R&D in the country.

Graph 3. R&D intensity in the EU-25, USA, Portugal and Japan - 2002

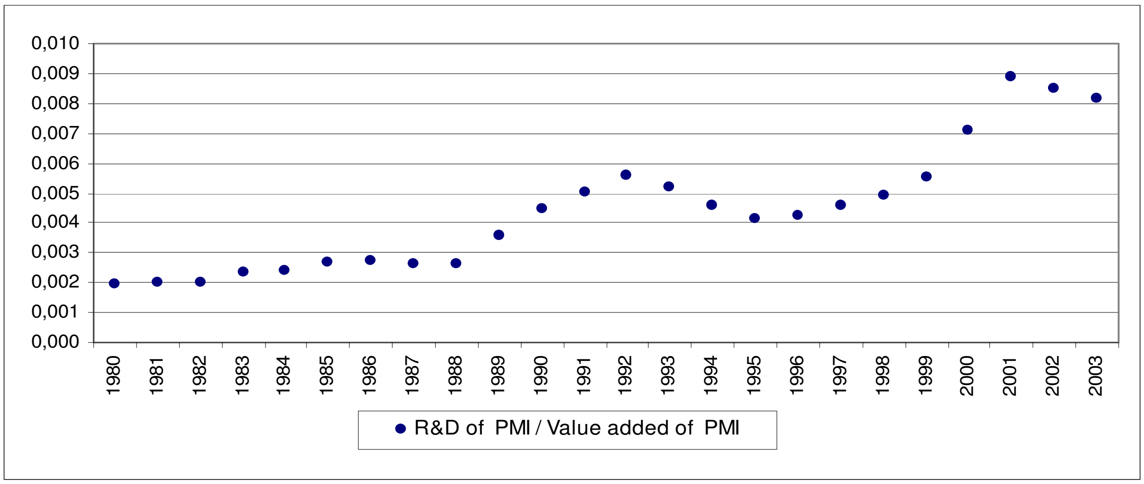


Source: Science and Technology – Statistics in Focus (2005), Eurostat.

[13] A decline in the weigh of the industry in the overall economy.

The European Innovation Scoreboard (European Commission, 2006c) ranks economies according to a summary innovation index (SII) that combines five different dimensions, grouped in inputs and outputs.[14,15] As far as Portugal is concerned, it is part of a group (Slovenia, Czech Republic, Lithuania, Poland, Latvia, Greece and Bulgaria) of catching-up countries with SII scores well below the EU-25, albeit with a faster than average improvement in innovation performance. Public R&D contributed significantly to that end, albeit the data of private R&D intensity in manufacturing overall shows also considerable improvements since 1980.

Graph 4. Private R&D intensity in Portuguese mananufacturing industry, 1980-2003



Source: Own elaboration based on "Estatísticas Industriais" (1980-1989), "Estatísticas das Empresas" (1990-2003), "Anuário Estatístico" (1986-1989) and "Anuário Estatístico de Portugal" (1990-2003) from the National Statistics Institute of Portugal, as well as data from the R&D Survey by the "Observatório da Ciência e do Ensino Superior".

[14] At the innovation inputs level: Innovation drivers (5 indicators, measuring the structural conditions of the innovation potential), knowledge creation (4 indicators, measuring the investments in R&D activities, considered key elements in a successful knowledge-based economy), innovation and entrepreneurship (6 indicators, measuring the efforts towards innovation at the firm level). Innovation outputs include two dimensions, namely applications (5 indicators, measuring the performance, expressed in terms of labour and business activities, and their value added in innovative sectors) and intellectual property (5 indicators, measuring the achieved results in terms of successful know-how).

[15] A comparison with the US and Japan indicates that both are still ahead of the EU-25 in terms of innovation performance.

Looking at the data, it is clear the positive trend from 1988 onwards, in spite of the slight decline in early 1990s and 2000s mainly associated with the international crisis (Biscaya *et al.*, 2002). Neverthless, business R&D is still realively lower than in the EU. The small size of the firms has been advanced as one of the possible explanations for the low levels of R&D in Portuguese industry. Another set of reasons are related to the industrial structure, namely the strong concentration in low-tech sectors (Gonçalves *et al.*, 1999), as we shall see in the next section. Indeed, the importance of medium and high-tech sectors on the innovation performance of country is clear when we look the distribution of the investments in R&D. For the case of the PMI, the table shows a concentration in the high-technology and medium-high-technology industries. Machinery equipment, electric and optical equipment as well as the transport equipment industries represented in 2003 about 45% of the total expenditure in R&D carried out by the PMI. Coke and petroleum, chemicals and products must also be mentioned on account of their 25%.

Table 4. Structure of expenditure in R&D (current prices), 2003

Branch of Economic Activity	R&D (thousand €)	R&D (%)
D – Manufacturing	150.957,9	100
DA – Food, beverages and tobacco	5.651	4
DB – Textiles	10.509,9	7
DC – Fur and leather	733,3	-
DD – Wood, cork and products	3.718,0	2
DE – Pulp, paper, paper products, publishing and printing	2.987,7	2
DF – Coke and petroleum DG – Chemicals and products	37.249,0	25
DH – Rubber and plastics	11.032,1	7
DI – Non-metallic mineral products	6.830,0	5
DJ – Basic metals and metallic products	2.833,5	2
DK – Machinery equipment, n.e. c.	15.874,7	11
DL – Electric and optical equipment	44.518,3	29
DM – Transport equipment	7.346,8	5
DN – Other manufacturing industries	1.673,6	1

Source: Adapted from the R&D Survey (2003) by the "Observatório da Ciência e do Ensino Superior".

Note: Due to statistical secrecy reasons, the results of subsections DF and DG are presented as a whole.

3.1.3. Industrial structure

Portugal is often characterised as specialising in labour intensive industries. An analysis of the employment structure within manufacturing reinforces this idea. In 2003, textiles still accounted for 26 percent of employment in Portuguese manufacturing. Then apperas food, beverages and tobacco followed by basic metals and metallic products with their 12 and 10 percent of the manufacturing employment. Machinery equipment, electric and optical equipment and transport equipment altogether account for only 15 percent of the manufacturing employment in 2003.

Table 5. Structure of employment, 2003

Industry	Nº employees	Employees (% on total)
D – Manufacturing	886.253	100
DA – Food, beverages and tobacco	106.277	12
DB – Textiles	222.602	26
DC – Fur and leather	62.333	7
DD – Wood, cork and products	48.611	5
DE – Pulp, paper, paper products, publishing and printing	53.428	6
DF – Coke and petroleum	2.136	-
DG – Chemicals	21.715	2
DH – Rubber and plastics	24.511	3
DI – Non-metallic mineral products	64.771	7
DJ – Basic metals and metallic products	91.519	10
DK – Machinery equipment, n.e. c.	43.124	5
DL – Electric and optical equipment	49.027	6
DM – Transport equipment	34.168	4
DN – Other manufacturing industries	62.031	7

Source: Own elaboration based on “Estatísticas das Empresas” (2003), from the National Statistics Institute of Portugal.

The analysis of the PMI in terms of value-added reveals once more the weight of textiles, food, beverages and tobacco, with 14 and 13 percent of the PMI value-added in 2003. Machinery equipment, electric and optical equipment and transport equipment, account altogether for 19 percent of the value added in 2003.

Table 6. Structure of value-added (current prices), 2003

Industry	VA (thousand €)	VA (%)
D – Manufacturing	18.470.272	100
DA – Food, beverages and tobacco	2.604.169	13
DB – Textiles	2.638.017	14
DC – Fur and leather	668.708	4
DD – Wood, cork and products	806.520	4
DE – Pulp, paper, paper products, publishing and printing	1.803.996	10
DF – Coke and petroleum	523.801	3
DG- Chemicals	1.049.753	6
DH – Rubber and plastics	719.447	4
DI – Non-metallic mineral products	1.711.180	9
DJ – Basic metals and metallic products	1.719.353	9
DK – Machinery equipment, n.e. c.	1.026.060	6
DL – Electric and optical equipment	1.346.985	7
DM – Transport equipment	1.018.573	6
DN – Other manufacturing industries	833.709	5

Source: Own elaboration based on "Estatísticas das Empresas" (2003), from the National Statistics Institute of Portugal.

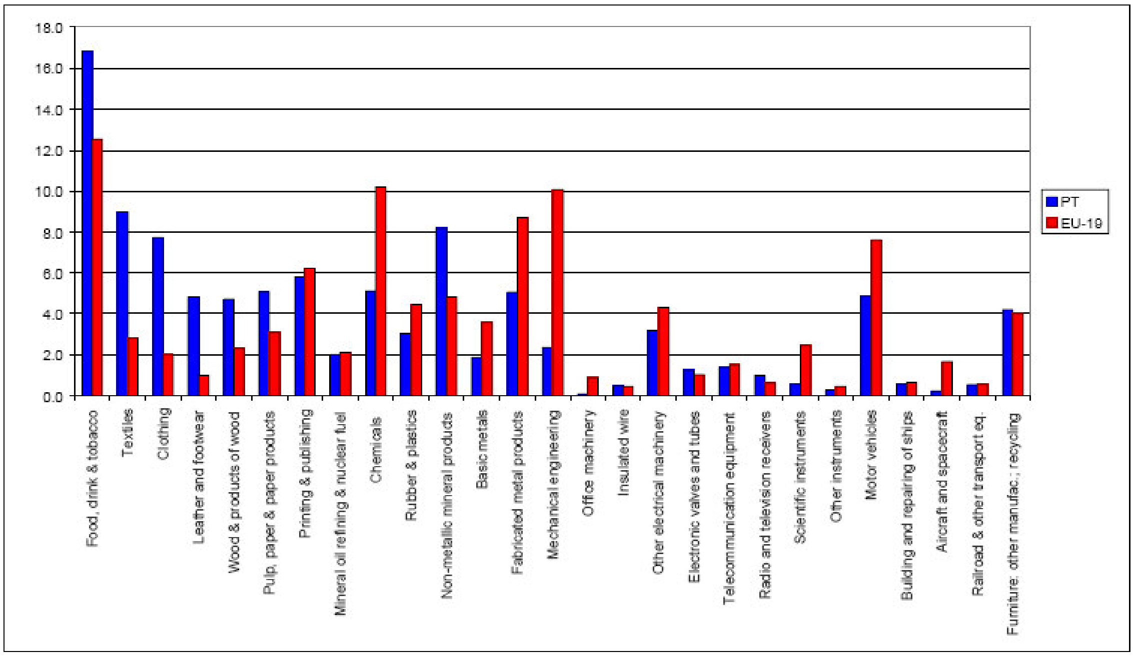
Regarding specialisation in perspective with Europe, three groups of countries can be identified within the EU-15. The first one includes countries specialised in high labour skill sectors (Belgium, France, and Luxembourg) and high to intermediate labour skills (Denmark, Finland, Sweden and to a lesser extent the United Kingdom). The second group includes countries specialised in the two lowest categories of labour skills and includes Portugal (apart from Austria, Spain, Greece and Italy). Note that in the study by DG Enterprise of the European Commission (2006b), Portugal is characterised as specialising[16] in

[16] The indicator of sectoral specialization of EU-15 member states here presented compares a country's value-added shares across industries with the average EU-15 industry's shares. The indicator is defined, for country 'i' and industry 'j', with VA being value added and EU corresponding to the EU-15, as to indicate specialization equal to the EU average if the value is 1 for a given industry. The higher the value of the indicator, the higher the country's specialization compared with the EU average.

$$S_{i,j} = \frac{\dfrac{VA_{i,j}}{\sum_j VA_{i,j}}}{\dfrac{VA_{EU,j}}{\sum_j VA_{EU,j}}}$$

leather and footwear, clothing, textiles, wood and products of wood, financial intermediation, radio and television receivers. Finally, there is a group of countries without a clear specialisation profile (Germany, the Netherlands and Ireland). This implies that the distribution of value added is very similar to the one of the EU-15 as a whole.

Graph 5. Sectoral share in manufacturing value added (%) (Mean 2000-02), Portugal and EU



Source: European Commission (2006b)

Following the OECD High-tech classification of manufacturing industries[17], we may analyse the PMI's employment structure at this level. In this regard, great stability is verified over the years, where the low-technology and medium-low-technology industries are visibly dominant. These industries as a whole represent in 2006 about 84% of the total employment in the Portuguese manufacturing, while in the set of 4 countries considered in the table they don't represent more than 58%.

[17] In appendice 1 we provide the OECD High-tech classification of manufacturing industries.

Table 7. Employment structure in terms of industries by technological intensity (%)

<table>
<tr><th rowspan="2">Global Technological Intensity</th><th colspan="4">Portugal</th><th colspan="3">Germany+UK+Italy+France*</th></tr>
<tr><th>1985</th><th>1994</th><th>2003</th><th>2006</th><th>1985</th><th>1994</th><th>2006</th></tr>
<tr><td>High-tech industries</td><td>3</td><td>3</td><td>3</td><td>2</td><td>9</td><td>9</td><td>7</td></tr>
<tr><td>Medium-high-tech industries</td><td>12</td><td>13</td><td>13</td><td>14</td><td>32</td><td>33</td><td>35</td></tr>
<tr><td>Medium-low-tech industries</td><td>26</td><td>25</td><td>21</td><td rowspan="2">84</td><td>25</td><td>24</td><td rowspan="2">58</td></tr>
<tr><td>Low-tech industries</td><td>59</td><td>59</td><td>63</td><td>34</td><td>34</td></tr>
<tr><td>Total manufacturing</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td></tr>
</table>

Source: Adapted from Godinho and Mamede (2004) except 2003 (authors' own calculations based on values of "Estatísticas das Empresas" (2003) from the National Statistics Institute of Portugal) and 2006 (own calculations based on values of "Science, technology and innovation in Europe" (2008) from Eurostat).

* Average from Germany, United Kingdom, Italy and France

As seen, the structure of the PMI shows clearly the weight of low and medium to low technology sectors (Godinho e Mamede, 2004). Neverthless, the relationship between structure and productivity must not disregard the starting level. An increase in the weight of high and medium to high technology industries of about 1 percent may have significant impact on economies with a very low starting point (Kaloudis and Smith, 2005). Otherwise, even if an industry's employment share remains constant over time, there may have been a lot of entry and exit of firms and innovation (products and processes) in that industry. As we mentioned in the previous section, high and medium to high technology industries are the most highly innovative within Portuguese manufacturing. These aspects need be considered.

Hence, the emergence of competitors with a broad spectrum of comparative advantages in industrial activities has put the issue of the manufacturing industry's future in industrialised countries on the agenda. The discussion of whether Europe can hold on to manufacturing assumes particular relevance for economies such as the Portuguese one, strongly open and relatively specialised in labour-intensive sectors.

3.2 Productivity, R&D and structural change: an empirical application

In the previous section 3.1 we highlighted the increase in PMI's productivity as well as the developments regarding innovation and structural change. Following the literature reviewed in section 2, three hypotheses are tested on the Portuguese manufacturing over the period 1980-2003:

H1) Public R&D activity has a positive impact on manufacturing productivity;

H2) Business R&D in the high-technology and medium-high-technology industries has a positive impact on manufacturing productivity;

H3) An increase of the high-technology and medium-high-technology industries on the manufacturing employment has a positive impact on the manufacturing productivity.

3.2.1 Econometric model

If an exact innovation model in all its multiple dimensions was available, we would be able to fully understand the complex nature of innovation (Mairesse, 2004). However, such a model does not exist. Nevertheless, in Mairesse (2004) words, "it is worth trying to account for innovation differences, even in a crude and simplified manner."

Since productivity is, among other things, a result of innovation, and innovation is, among other things, a result of R&D (Mairesse and Mohnen, 2002), we present a multiple regression model that allows us to quantify the relation between a dependent variable (Y) and a set of independent variables (X_0, X_1, X_2,..., X_n) through the estimation of their parameters (β_0, β_1, β_2…, β_n):

$$Y_t = \beta_0 + \beta_1 X_{t1} + \beta_2 X_{t2} + ... + \beta_n X_{tn} + u_t \quad \text{, with } X_0 = 1 \text{ ; } t = 1,2...,T$$

or (1)

$$Y_t = \beta_0 + \sum_{i=1}^{n} \beta_i X_{ti} + u_t \quad \text{, with } X_0 = 1 \text{ ; } i = 1,2...,n \text{ ; } t = 1,2,...T.$$

Based on equation (1), we developed an econometric model in order to explain the PMI's labour productivity.

The econometric model includes public R&D activity by the Portuguese State (H1) and business R&D in medium and high-tech industries so as to analyze the relation between R&D and the PMI's labour productivity, giving particular enphasis to R&D in medium and high intensive sectors (H2).

To test Hypotheses 3 we included as a variable the weight of medium to high-tech industries on total manufacturing employment, as this group of industries registered a slight increase over the period under analysis. In our study we considered the machinery equipment (ME), electric and optical equipment (EOE) and transport equipment (TE) sectors, which are classified by OECD as medium to high-tech intensive sectors.

$$Y_t = \beta_0 + \beta_1 X_{t1} + \beta_2 X_{t2} + \beta_3 X_{t3} + u_t \quad (1.1)$$

with $X_0 = 1$; $t = 1, 2, ...24$

where:

- Y: stands for PMI labour productivity, which is represented by the logarithm of the ratio between the value added of PMI (constant prices: base year 1986) and employment in the PMI;
- X_1 : stands for public R&D intensity which is represented by the logarithm of the ratio between the Portuguese State's expenditure in R&D and the value added of PMI;
- X_2 : stands for the private intensity in R&D of ME, EOE and TE, which is represented by the logarithm of the ratio between private expenditure in R&D by these three industries and the value added relative to ME, EOE and TE;
- X_3 : stands for the proportion that ME, EOE and TE as a whole have in the total employment of the PMI, which is represented by the logarithm of the ratio between employment in these three industries and total employment in the PMI.

We further introduced a number of lags for R&D related variables (X_1 and X_2). The introduction of lags is based on the fact that R&D expenditures may well take time to affect output. Indeed, investments in R&D do not normally produce immediate results because time is necessary before new knowledge can be developed, so that it can be disseminated and commercialized in the economy (Griliches, 1979).

Seeing that a significant number of studies have demonstrated that this lag varies on average between one and four years (Mansfield *et al.*, 1971; Pakes and Schankerman, 1984; Acs and Audretsch, 1988), we also estimate our model considering a temporal lag of one, two, three and four years for the variables related to R&D intensity (X_1 and X_2).

As referred previously, the data used in the study are mainly from The National Statistics Institute of Portugal (*Instituto Nacional de Estatística*) and the R&D Survey from the Science and Higher Education Observatory (*Observatório da Ciência e do Ensino Superior*). In this study, we had to overcome a difficulty caused by a new methodology introduced by the National Statistics Institute of Portugal in 1990 with regard to data collection. Therefore, it was indispensable to extrapolate data prior to 1990, in order to ensure a single and uniform sequence of information.

3.2.2. Estimation results

Table 8 presents the values obtained from the estimation of the model through the method of ordinary least squares (OLS). When no lags are considered, column (i) shows us that the elasticity of the PMI's labour productivity (Y) relative to variables X_1, X_2 and X_3 is 1.0284, 0.7047 and -0.7852 respectively. These results confirm Hypothesis 1, since Y presents a positive correlation with public R&D intensity by the Portuguese State (X_1). Hypothesis 2 is equally confirmed because, as we can see in Table 8, when private intensity in R&D by ME, EOE and TE increases 1%, then Y will rise by 0.7047%. Hypothesis 3 on the other hand is not confirmed. The variable X_3 related to the weight of the employment in medium and high-tech sectors appears negatively connected to productivity, but it is not statistically significant.

The independent variables as a whole reflect a good explanatory capacity for the PMI's labour productivity, once that $F_{Observed}$ is higher than $F_{Critical}$ at the 5% significance level. The high R^2 reflects a good adjustment of the model. In this particular case, 85.22 percent of the total variation in the PMI's labour productivity is explained by the independent variables considered in the model. As for the possible presence of an autocorrelation of errors, we observed a positive autocorrelation[18] ($p > 0$), once that Durbin-Watson's value ($d = 0.4728$) falls in the interval $]\, 0; d_L \,[$[19].

[18] In this situation, an increase in the labour productivity in the period t generates a positive impact on the residue of the following period (period t +1).

[19] The value of d_L with a 5% significance level is given by 1.101.

Table 8. Estimation results[20]

Variable	Parameter	(i)	(ii)1*y* lag	(iii)2*y* lag	(iv)3*y* lag	(v)4*y* lag
X_0	β_0	4.1631** (2.8379)	3.3048** (2.4053)	2.9816** (2.4310)	2.9294** (2.8095)	2.9002* (3.0628)
X_1	β_1	1.0284 (1.5187)	**1.0856*** (1.7430)**	**0.8581*** (1.8808)**	**0.7017** (2.2216)**	**0.6484** (2.4176)**
X_2	β_2	**0.7047** (2.3861)**	**0.5939** (2.2660)**	**0.6155* (3.1753)**	**0.6347* (4.6363)**	**0.5727* (4.9456)**
X_3	β_3	-0.7852 (-0.5663)	-1.1523 (-0.8883)	-0.8530 (-0.8772)	-0.5919 (-0.8068)	-0.3875 (-0.5928)
Observations		24	23	22	21	20
R^2		0.8522	0.8433	0.8463	0.8747	0.8938
Durbin-Watson		0.4728	0.4720	0.3938	0.3986	0.5965
$F_{Critical}$**		3.10	3.13	3.16	3.20	3.24
$F_{Observed}$		38.4393	34.0836	33.0371	39.5581	44.8864

Notes: Tvalues between brackets. In column (i) the model is estimated without any lag, in column (ii) with a 1-year lag for variables X_1 and X_2, in column (iii) with a 2-year lag, in column (iv) with a 3-year lag and in column (v) with a 4-year lag.
* Significance at 1% ; ** Significance at 5% ; *** Significance at 10%

Considering the model with lags for R&D related variables (X_1 and X_2), Hypothesis 1 and Hypothesis 2 are once again confirmed. With regard to Hypothesis 1, the return from the public R&D activity reaches its peak one year after the investment has been made (an increase in X_1 of 1 percent in period t leads to a rise of Y by about 1.086 percent in period t+1). From that point, an increase in the PMI's labour productivity resultant from the public activity in R&D becomes increasingly smaller, because a significant part of the impact of this investment has already been amortized. As for Hypothesis 2, private intensity in R&D by ME, EOE and TE is still positively correlated with the PMI's labour productivity, but the greatest contribution to productivity growth in given in the initial year. This situation can be justified by the fact that direct impact and the inherent spillovers from this investment occur in a relatively shorter period of time.

[20] The estimation was carried out with the EViews software.

The econometric model still presents a good adjustment and the independent variables as a whole still reflect a good explanatory capacity towards the dependent variable (only X_3 is not statistically significant). This model maintains a positive autocorrelation of the errors once that Durbin-Watson's value (with a 5% significance level) in any temporal lag falls in the interval $]\,0\,;\,d_L\,[$[21].

4. Discussion and implications

Our model makes many simplifying assumptions, but its main virtue is that it takes into consideration the indirect impact of public R&D as well as of medium and high-tech industries R&D in other sectors where the R&D effort is made. Our results confirm the importance of governement's R&D and of business R&D in the medium to high-tech sectors, as they stimulate productivity growth. We further reveal that the return from the public R&D activity reaches its peak one year after the investment has been made, while for private intensity in R&D by ME, EOE and TE the greatest contribution to productivity growth is given in the initial year. Hence, the direct impact and the inherent spillovers from the private expenditure in R&D occur in a relatively shorter period of time than that of public investment. R&D is overwhelming important, but, R&D expenditures may be only one part of the story behind the Portuguese backlog. Factors such as absorptive capacity, interactions within the S&T system, regulation and stability may be just as important in achieving the TP ambition.

Regarding the role of structural change, the results deserve an in-depth analysis and the conclusions are not straightforward.

In the countries examined by Kaloudis and Smith (2005), there has been a clear tendency for the share of low-tech industries in manufacturing to decline during the period 1980-1999, while the share of high-tech industries has increased. This applies to both production and employment. However, they concluded that among the OECD countries studied, structural change within manufacturing is not the direct cause of the growth process in advanced OECD economies. In our case we did not identified a decline or (growth) in the weight

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[21] ii) $d = 0.4720$; $d_L = 1.078$; $d_U = 1.660$ $\Rightarrow$ $d < d_L$.
iii) $d = 0.3938$; $d_L = 1.053$; $d_U = 1.664$ $\Rightarrow$ $d < d_L$.
iv) $d = 0.3986$; $d_L = 1.026$; $d_U = 1.669$ $\Rightarrow$ $d < d_L$.
v) $d = 0.5965$; $d_L = 0.998$; $d_U = 1.676$ $\Rightarrow$ $d < d_L$.

of technology intensive industries. Probably for that reason we could not confirm Hypothesis 3. Othewise, the fact that high-tech sectors are growing faster than medium or low-tech sectors in manufacturing output, does not necessarily mean that high-tech contributes more to overall manufacturing growth or productivity growth. High-tech sectors are small, so even high growth rates can have a relatively diminutive overall impact.

Based on our findings for Hipothese 3, we cannot hypothesize that productivity growth was primarily rooted on the creation of new sectors. Overwhelming important has been probably the internal transformation of sectors which already existed and/or are growing. Hence, one must avoid the views that emphasize excessively the role of high-tech sectors in economic growth, which often underestimate processes of change and needs in those sectors of the economy with low R&D investments. Finally, there has been structural change at the level of the economy as a whole, with a sustained risen in the share of services, and this rise does not support the high-tech argument, since sevices in general tend to be considered less R&D intensive than high-tech manufacturing. Moreover, a developed service sector may well contribute significantly to manufacturing productivity, and this fact was not taken into account in our analysis.

But, as refered previously, even if an industry's employment share remains constant over time, there may have been a lot of entry and exit of firms and innovation (products and processes) in that industry. We verified that the innovation developments in the industries under consideration had positive impact on the productivity evolution in the time period analysed. The dynamisation of business R&D in the Portuguese manufacturing relies substantially on the dynamics of medium to high-tech industries, even if they do not gain considerable weight in the total employment or value-added.

Finally, from the analysis it is possible to derive future research avenues. As demonstrated by several studies, there has been a clear tendency for the share of low-tech industries in manufacturing to decline, while the share of high-tech industries has increased. It is nevertheless important to confront the claims of high-tech approaches with the evidence.

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Appendice 1

High-tech classification of manufacturing industries

Global Technological Intensity	Economic Activity	Avergae R&D Intensity
High-technology	• Aeronautics and aerospacial • Pharmaceutic products • Office equipment and computing • Radio, TV and communication equipment • Medical instruments and optical	7,7% – 13,3%
Medium-high technology	• Machinery and electric equipment • Motorvehicles • Chemicals, except pharmaceutical industry • Rail and transport equipment n.e. • Other machinery and equipment	2,1% – 3,9%
Medium-low technology	• Construction and naval repair • Coke, Petrol and nucler • Non-metallic mineral products • Basic metals and metallic products • Metallic products (except machinery and equipment)	0,6% – 1%
Low-technology	• Recycling • Pulp, paper, paper products, publishing and printing • Food, beverages and tobacco • Textiles • Fur and leather • Wood and cork products	0,3% – 0,5%

Source: OECD based on NACE rev. 1.1.