TOWARDS A UNIVERSITY AGENDA ON ENGINEERING POLICY AND THE MANAGEMENT OF TECHNOLOGY

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A version of this paper was presented at the 4th Intl. Conf. On technology Policy and Innovation, Curitiba, Brazil, 30 August-2 September, 2000

Paper accepted for publication in the **Int. J. of Technology, Policy and Management**,
EDITED BY PROF G. BEROGGI, DELFT UNIVERSITY OF TECHNOLOGY, NL
DECEMBER 2000

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ABSTRACT

In view of the current socio-economic context, in which innovation is a key driving force for sustainable development, which challenges are facing Technical Universities to enhance and nurture innovation and better contribute to help developing and exploiting engineering, science and technology? This broad question has motivated the work behind the present paper, which considers the development of university research and education on *engineering policy* and the *management of technology* to **complement** current engineering disciplines. It is argued that these areas represent an *emerging engineering discipline,* which helps promoting *learning trajectories* for the *inclusive development* of society, but also to contribute for the use of new *metrics for knowledge.* The analysis builds on the experience of developing post-graduate education in *engineering policy and management of technology* at the *Instituto Superior Tecnico* of the *Technical University of Lisbon,* in a context much influenced by a *dynamic of change* and a necessary *balance between the creation and diffusion* of knowledge.

KEYWORDS: *engineering policy; management of technology; innovation; technological change*

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TOWARDS A UNIVERSITY AGENDA ON
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Pedro Conceição and Manuel Heitor

1. Introduction

In previous papers we have discussed extensively the important strategic role that universities can play in helping nations to meet public goals (Conceição, Heitor and Oliveira,1998; Conceição and Heitor, 1999; Caraça, Conceição and Heitor 1998, 2000; Santos et al.,1998). Our analysis has been based on the way organizations promote "learning", where learning is understood as the mechanisms through which knowledge is produced and diffused (Rosenberg, 2000), including such diverse aspects as public safety, quality of life, health care, environmental protection and economic competitiveness (e.g. Clark, 1995, 1998; Readings, 1996; Lucas, 1996; Noll, 1998; OECD 1999). However, in face of a globally expanding and highly competitive knowledge-based economy, traditional suppliers of knowledge such as schools, universities, and training organizations, as well as businesses and knowledge based organizations in the public sector (growing users of knowledge), are urgently seeking fundamental insights to help them nurture, harvest and manage the immense potential for their knowledge assets for capability to excel at the leading edge of innovation. In this context, this paper is focused on emerging trends for advanced education and research in the fields of **technology policy and management** in *engineering schools*, in a way to contribute for the challenges faced by engineering and technology to enhance innovation.

The understanding of *innovation* adopted in our work encompasses **the way in which firms and entrepreneurs create value by exploiting change**. Change can be associated with technological advances, but also with modifications of the regulatory framework of an industry, shifts in consumer tastes, demographic changes, and even major alterations of global geopolitics. In this context, our approach is to discuss important trends in *engineering education and research* that are likely to influence the environment in which firms conduct their business and, consequently, determine the conditions and opportunities for innovation. The analysis is applied to the specific Portuguese context (as described by Conceição and Heitor, 2000), but may be valid for international developments and comparisons.

The work includes four main parts. First we look at the international **context and dynamics**, and this is particularly based on the recent framework under discussion by the OECD FUTURE Program. It should be noted that we use the **conceptual background** developed by Conceição et al. (1998, 2000) based on recent research and current understanding of knowledge for development and related learning dynamics, and building on the systemic view of the emerging role of *systems of innovation and competence building* for the development of our society. The discussion frames the issue of the need to promote "**inclusive development**", that is, of the need for a process of development that

includes every citizen in any region, as a problem that goes beyond the creation of conditions to generate knowledge. The most important problem concerns the *sharing and diffusion of knowledge*, and efforts should be channeled towards the understanding of the conditions for globally integrated learning processes. **Learning**, in this context, reflects the idea of sustained knowledge creation and diffusion. We contend that the challenge is to make this a feature of the entire global economy. In this context, we establish that national or regional learning depends on the existence of **social capital**, which is defined by *networks* and by *institutions*. Institutions govern the interactions among the nodes of the networks, whether the nodes are composed of people or organizations (firms, universities, and local government, for example).

Second, we analyze current trends and **challenges** for science, technology and innovation policy, which provide us with the necessary empirical evidence to discuss the need for new indicators and, in general, **new metrics for knowledge**, which we discuss in section 3. We conclude by discussing avenues for **innovation policy towards an inclusive learning society**, making use of the specific Portuguese situation.

2. The Context: Engineering and Technology for Innovation

We consider in this part topics that are critical determinants affecting most of the countries in the world. The first is **globalization**. Secondly, we look at **technological change** and the growing importance of knowledge. Thirdly, we look at **institutional change** and consider the **changing role of the state**.

Our approach to deal with each of these issues is to describe in general terms the context and then to attempt to place Portugal in that context. This is because the fact that countries have different levels of income is clearly self-evident. Therefore, it is equally obvious that each country has followed its own trajectory, within the context of an existing techno-economic paradigm and the specific innovation system of the nation. We look here at some evidence on the translation of different paths in the economic performance of countries. We begin with an interpretation of the major techno-economic paradigms, illustrated in Table 1.

Table 1 shows five important techno-economic paradigms. While the paradigms presented result from one interpretation, they illustrate with some empirical evidence the features of techno-economic paradigms presented before. Let us consider the first techno-economic paradigm. This corresponds to the emergence of the Industrial Revolution, as mechanization was increasingly incorporated in manufacturing, especially in some industries such as textiles. However, the technologies well diffused and used within this paradigm presented some important limitations for the increase of the scale and output of the productive activity. Most firms remained small and local. Process control was poor and hand operated machines did not allow for output of reliable quality. Naturally, advances in steam

Table 1- Tentative Sketch of Major Techno-Economic Paradigms

Approximate Period	Description	Key Sectors	Economic Organization
1770s to 1840s	Early Mechanization	Textiles, Canals, Turnpike Roads	Individual entrepreneurs and small firms; local capital and individual wealth
1830s to 1890s	Steam Power and Railway	Steam Engines, Railway, World Shipping	Emergence of large firms with unprecedented size; limited liability corporations and joint stock ownership
1880s to 1940s	Electrical and Heavy Engineering	Electrical Engineering, Chemical Process Industries, Steel ships, Heavy armaments	Giant firms, cartels, trusts; mergers and acquisitions; state regulation and enforcement of anti-trust; professional management teams
1930s to 1980s	Fordist Mass Production	Automobiles, Aircraft, Consumer Durables, Synthetic Materials	Oligopolistic competition; emergence of multinational corporations; rise of foreign direct investment; vertical integration; technocratic management styles and approaches
1970s to …	Information and Communication	Computers, Software, Telecommunications, Digital Technologies	Networks of large and small firms based increasingly on computer networks; wave of entrepreneurial activity associated with new technologies; strong regional clusters of innovative and entrepreneurial firms

Source: Adapted from Table 3.5, Freeman and Soete (1997).

engine technologies and machinery were already taking place, but it took a long time until they were ready for fruition. When these important technologies matured to the level that made their economic utilization possible, they became the core technologies of the second techno-economic paradigm. The second paradigm, based on steam engine and on machinery, ameliorated some of the previous limitations, and created in itself the germ for new types of economic organization, as Table 1 details.

If we cross the techno-economic paradigms with geography, then we start joining together the ideas of technological trajectory and national innovation system. Britain led the two first techno-economic paradigms. In this context the US and Germany, for example, were "latecomers". Still, they became leaders in the third techno-economic paradigm, with Japan also leading in the fourth and the US arguably retaining the lead alone in the fifth, although we look at this claim in detail below. Therefore, the concept of *latecomer industrialization* is, in itself, relative and mutable, but now clearly strongly influenced by the challenges brought through the emergence of globalization and technical change.

2.1 Globalization

To summarize this broad topic, *globalization* corresponds to the growing integration of the world's economies – enhanced by institutional and technological changes. This integration has led to a growth in world trade, more open global financial transactions, higher levels of international investment flows, growing interdependency of large firms, among other economic factors. Still, the world distribution of wealth remains highly unequal, which has contributed to a backlash against the trend towards globalization and against some of the international institutions that (rightly or wrong) have come to be perceived as symbolizing globalization. Additionally, new global problems are calling for higher international coordination, beyond the national self-interest of the richest countries.

The context of globalization necessarily invites international comparisons across countries. A popular source, especially in the business press, is the Competitiveness Index, developed by the World Economic Forum (1999). According to this source, Portugal typically ranks about the middle of the table. Out of 59 countries, Portugal ranked 30th in 1997, 26th in 1998 and 27th in 1999. The Competitiveness Index is, naturally, a subjective measure, and plays to the biases of the entity that produces the index. More objective measures are associated with comparisons of output per capita and labor productivity. These measures are not without faults either, given the difficulty of constructing comparable figures across diverse countries.

Productivity, in a way, is probably the best indicator of the extent to which a nation is taking full advantage of the conditions provided by the existing techno-economic paradigm. In this context, a recent study by Ark and McGuckin (1999) tackles international comparisons of productivity and income in a particularly careful way, especially in finding comparable measures across countries. They also link labor productivity with output per capita following a common decomposition procedure. While the

relationship between these two variables may seem obvious, in fact there are many subtleties involved. For example, a country that is very productive but where workers engage in productive activities fewer hours than a less productive country can result in an output per capita that is higher in the second country. Table 2 shows their results presented in this work.

Table 2- Decomposition of GDP per Hour Worked into Effects of Working Hours, Labor Force Participation and GDP Per Capita, 1997

	GDP **per hour worked** as a % of the OECD Average	Effect of working hours	GDP **per person employed** as a % of the OECD Average	Effect of unemploy-ment	Effect of labor force as a % of the working age population	Effect of working age population as a % of the total population	Total effect of labor force participation	GDP **per person** as a % of the OECD Average
	(1)	(2)	(3)=(1)+(2)	(4)	(5)	(6)	(7)=(4)+(5)+(6)	(8)=(3)+(7)
Australia	**96**	0	**96**	-1	2	0	1	**97**
Austria	**102**	-4	**98**	3	-2	1	2	**100**
Belgium	**128**	-5	**123**	-3	-19	-1	-22	**101**
Canada	**97**	2	**98**	-2	2	2	2	**100**
Denmark	**92**	0	**92**	1	9	1	11	**103**
Finland	**93**	0	**94**	-7	2	0	-5	**88**
France	**123**	-9	**113**	-6	-9	-2	-17	**97**
Germany	**105**	-5	**100**	-3	-4	2	-4	**96**
Greece	**75**	-4	**71**	-2	-11	1	-12	**58**
Ireland	**108**	5	**113**	-4	-12	-3	-18	**95**
Italy	**106**	-11	**96**	-5	-1	2	-5	**91**
Japan	**82**	10	**92**	4	6	4	14	**106**
The Netherlands	**121**	-26	**95**	2	-4	2	0	**96**
New Zealand	**69**	8	**77**	1	3	-1	2	**79**
Norway	**126**	-17	**109**	4	12	-4	12	**122**
Portugal	**56**	2	**58**	0	1	1	2	**60**
Spain	**84**	13	**97**	-14	-13	2	-26	**71**
Sweden	**93**	-3	**89**	-3	6	-4	-1	**88**
Switzerland	**94**	0	**94**	3	12	1	17	**111**
Turkey	**36**	2	**38**	0	-8	-1	-9	**29**
United Kingdom	**100**	-9	**91**	0	3	-2	0	**92**
United States	**120**	-1	**118**	3	9	-2	10	**128**
EU-14	**103**	-5	**98**	-4	-4	0	-8	**90**

Source: Ark and McGuckin (1999). Summations may not add exactly due to rounding errors.

Portugal and Turkey have the lowest hourly labor productivity rate of the OECD. Portuguese hourly productivity is about half of the OECD average. Productivity in Greece is 19 points above Portugal's and Spain's productivity is 28 points above the Portuguese hourly labor productivity. Still, when one looks at GDP per capita, Greece's is actually lower than Portugal by two points and Spain's is only 11 points above Portugal.

Table 2 shows the variety of effects involved. Column (2) shows the impact of the number of hours worked. The summation of columns (1) and (2) produces the GDP per person employed. We see that Spanish and Japanese workers work longer hours than in most of the other countries. Per worker productivity in Spain, measured as GDP per worker, raises almost to the OECD level. Portuguese workers also work long hours, adding 2 points to the per hour productivity measures. In Italy, France, The Netherlands, Norway and the United Kingdom less hours of work reduce per employee productivity. Standards of living are determined not only by the number of hours worked and the productivity of each hour of work, but also by the "number of mouths to feed". The effect of the labor force participation connects per worker productivity and GDP per person. It is the effect of the labor force participation, for example, that brings down the income per capita of the productive and hard working Spanish workers: the combined effect of unemployment and the low labor force participation among the working age population take 26 points off the per worker productivity. The same happens in Greece, where 12 points are taken off the GDP per worker. In Portugal, both the effects of hours

worked and labor force participation are small and positive. It is, therefore, clear that the real challenge to increase the level of GDP per capita in Portugal is not so much a reduction of unemployment or, more generally, an increase in labor force participation (as in Spain, for example); it is really the increase in the fundamental hourly labor productivity. To understand these differences it is important to look at the existing dominant techno-economic paradigm, to which we will now turn.

That globalization is an unavoidable trend is conclusion all countries, including Portugal, recognize. However, both theory and practice suggest that there is no automatic assurance that small open economies that engage in trade are driven to promote innovation. As Grossman and Helpman (1991) indicate, innovation can indeed be promoted only if the forces of comparative advantage push the economy's resources towards activities that enable and enhance growth (R&D, more product variety, better quality of products and services, investments in human capital). Several trade and growth models show that a country that specializes (and may be driven to increase that specialization by comparative advantage incentives) in non-dynamic sectors that are behind the technological frontier can remain locked-in backward and stagnant industries.

In a context of globalization, understanding the factors above has become critical for the successful use of engineering, science and technology to promote innovation, and this has led our approach of developing an university agenda on *engineering policy and management of technology.*

2.2 Knowledge, Technology and the Digital Chimera

The advent of digital technologies has captured the minds of businessmen, policy-makers and many academics. The computer, new telecommunications devices and, more recently, the Internet are indeed powerful and impressive technologies. They are affecting people and firms in fundamental and permanent ways. Within this context, it is not surprising that many countries, regions and cities around the world are trying to catch the wave of the Internet and digital technologies. By most accounts, the achievement of regional economic development based on new information technologies results from a combination of efforts from the private and the public sector. Recently, public officials and decision-makers have been heavily pushing the development of initiatives geared towards the enhancement of the conditions that can lead to IT-driven prosperity. As the European Commissioner for Enterprise and the Information Society said in a recent speech: "Europe is in the middle of an economic revolution. This is the time for a call for action to both the private and the public sector in Europe. We must work for a strong European e-economy which realizes electronic services for the benefit of all" (Cordis, 2000).

While the US took the lead in the development and diffusion of digital technologies, and especially in finding and promoting ways to derive economic benefits from its usage, Europe is now catching up fast. By any measure, digital technologies are neither as diffused nor used as intensely as in the US, with the exception of mobile phones. Yet the growth rate in Europe is attracting investors and creating

a boom that does compare with the one that the US has gone through in the last few years (see Cornet, Milcent and Roussel, 2000). In fact, the European advantage in mobile telephony is seen as a potential important advantage in comparison with the US, since wireless Internet application are forecasted to increase in importance.

The emergence of the "information society" should clearly be understood from a deeper understanding of its role for development. Gordon (1999) concludes:

> "There has been no productivity growth acceleration in the 99 percent of the [US] economy located outside the sector which manufactures computer hardware, beyond which can be explained by price remeasurement and by a normal (and modest) procyclical response. Indeed, far from exhibiting a productivity acceleration, the productivity slowdown in manufacturing has gotten worse; when computers are stripped out of the durable manufacturing sector, there has been a further productivity slowdown in durable manufacturing in 1995-00 as compared to 1972-95, and no acceleration at all in non-durable manufacturing."

The fundamental question to be asked is that if computer associated firms can benefit from IT technological advances, why should not firms in other sectors do the same? It may take more time for these benefits to reveal themselves statistically in other industries, but eventually a spillover to other industries is likely to arise. As discussed above, anecdotal evidence already suggests that digital technologies are gaining momentum in terms of their economic weight and in the changes they are driving in people and firm's behavior. According to some, the computer and its associated digital technologies are part of a regime transition, following the pioneering formulation of Freeman and Perez (1986). This hypothesis suggests that *the emergence of a new radical technology requires a number of minor technological improvements, as well as institutional and social adjustments, to make its impact noted in the economy*. In brief, the emergence of a radical technology requires time. Historical analyses proposed by David (1990), among others, show that previous important technological breakthroughs took decades until they had a measurable economic effect. In his 1990 work, he focused on the substitution of electric motors for steam engines, and established a historical equivalence with the computer. More recently (David, 2000) he suggests that the same type of "delaying" mechanisms is at work today with digital technologies and the Internet. There have been attempts to formalize these hypotheses, under the emerging field of the study of General Purpose Technologies. The collection of essays in Helpman (1998) provides a snapshot of this literature.

In summary, while much attention has been devoted to digital technologies, the association between information technologies and productivity remains ambiguous. Still, it is undeniable that the spread of the computer and the Internet is profoundly changing the way people and firms behave and interact, with important consequences for policy and strategy. A more fundamental change at the start of the new millennium is the increasing importance of **knowledge for economic prosperity.** This feature of current developed countries corresponds to the continuing of a trend of acceleration of the importance

of the creation and diffusion of knowledge throughout the century. Beyond digital technologies, other technological breakthroughs, in many areas from the life sciences to the many fields of engineering, are likely to occur.

In this context, how does Portugal stand? In broad terms, the best characterization can be achieved by saying that the measures of the extent to which Portugal is engaged in the knowledge economy are relatively low, but that their growth in recent years has been dramatic. Figure 1 illustrates of this Portuguese feature. The horizontal axis represents the intensity of knowledge-based industries in the mid 1990s and the vertical axis the growth rate of these industries in the previous decade.

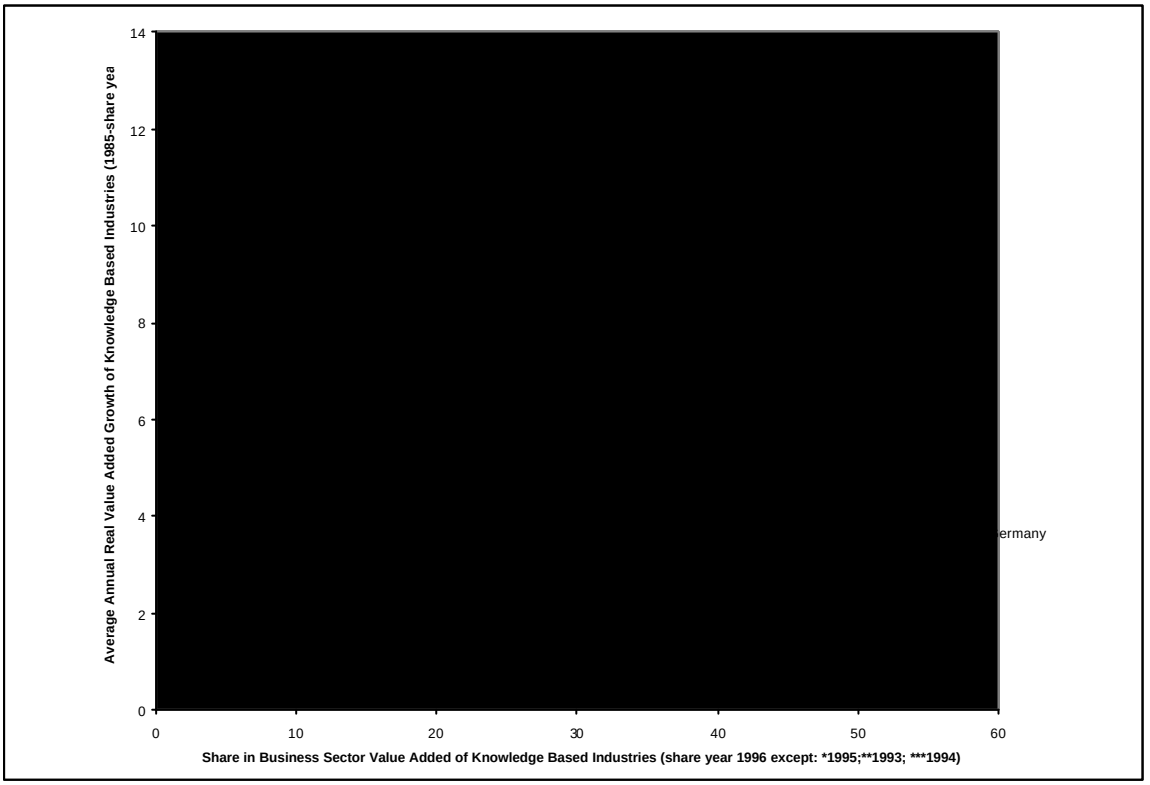

Figure 1- Knowledge Based Industries Intensity and Growth Source: OECD (2000).

Most countries are clustered at the bottom of Figure 1, with growth rates between 2% and 4% a year. The horizontal distribution of the countries shows Germany, the US, Japan and other leading developed countries to the right, with Spain and Greece to the left. In this context, Portugal and Korea stand out. The intensity of the knowledge-based industries in these countries is relatively low, especially in Portugal, which has the lowest level of knowledge-based industries. However, the growth rates for Portugal and Korea are remarkably higher, with the knowledge-based industries in Portugal growing close to 7% a year, and Korean knowledge based industries at more than 12% a year. The rate of growth of knowledge-based industries in comparable periods was of 3.1% for the European Union and of 3.5% for the entire OECD. The difference between the growth rates of Portugal and Korean is not as extraordinary as it may seem. In fact, the business sector as whole rose in Korea at 9.1% a year, while in Portugal the growth rate of the entire business sector was 4.6%.

Consequently, the difference between knowledge-industries growth rate and the entire business sector growth was of 2.3% for Portugal (or 50% of the business sector growth rate) while in Korea the difference was 3.4% (a higher difference, but only 37% of the entire business growth rate).

The perception of relatively low levels, but high growth rates, is confirmed by focussing on the technologies most relevant to the information society: information and communication technologies (ICT). Again, most countries show growth rates below 4%. The expenditures on ICT as a percentage of GDP in the US about 2% above the European average. Individual countries, such as Sweden, outperform the US, but most countries lag behind. Portugal's level of expenditure in ICT in 1997 is about 1% below the European Union average. However, as with knowledge-based industries, the growth rate in expenditures has been remarkable. In fact, Portugal is the leading OECD country in the growth rate of ICT expenditure from 1992 to 1997, with a growth rate of more than 10%. Most of this can be accounted for by increases in expenditures in telecommunications (about 9%). Expenditures in IT services and software are particularly low, below 1%. Only Turkey, Greece and Poland have lower shares of expenditure on IT software and services than Portuguese. The growth in this category has been equally dismal, below 2% a year.

Going back to the conceptualization of the knowledge-based or learning economy presented above, it can be said that, fundamentally, performance in this knowledge-rich competitive environments depends on the **quality of human resources** (their skills, competencies, education level, learning capability) and on the activities and incentives that are oriented towards the **generation and diffusion of knowledge**. In this regard the Portuguese situation is *clearly deficient*. This can be seen by looking at some indicators associated with the quality of human resources and with knowledge-generation activities.

According to the OECD (1998), Portugal has, after Turkey, the lowest share of the population aged 25-64 with at least an upper secondary education level. This share is about 20% for Portugal, while the OECD average is three times larger, at 60%. In the United States it is 76%, in Finland it 67% and in Ireland it is 50%. In the Czech Republic almost ¾ of the population aged 25-64 have at least an upper secondary education level. It is important to note that the deficiency is not so much on university or tertiary education. While the share of the Portuguese population with university education is also low (about 7%), it is only about half of the OECD average, and is comparable to that of countries such as Italy and Austria.

As regards university education, despite some "peaks" for countries such as the US and the Netherlands, the share of population with a university-level degree does not show as much variance as that of the share of the population bellow the upper secondary level. Portugal is characterized largely by a "dual" system, with a small share of the population with university education (but not that much smaller than in other countries) and an equally very small share of the population with education levels between university and upper secondary (inclusive).

Equally problematic is the flow of graduates in science and engineering, measured as the percentage of the labor force. In the mid 1990s the European Union average of the share of graduates in science and engineering was around 0.12% (OECD, 1998). The US share equaled the EU average, and Ireland had a share more than double the European Union average, at 0.25%. In 1996, the value for Portugal was 0.03%, or ¼ of the EU average.

Equating the quality of human resources with educational levels is, clearly, an incomplete characterization. Human capital includes, beyond education, features associated with health quality among others. Still, it is reasonable to expect the educational level to be associated with the quality of human resources and with human capital. Nevertheless, beyond human capital, which corresponds to the aggregation of an individual capacity for knowledge accumulation, developing a collective capacity for learning is as, if not more important, than individual learning Wright (1999).

Instead of individual or even aggregated human capital, a further important concept for learning seems to be social capital The importance of social capital, while still controversial, is increasingly being seen as an important determinant of economic performance and, especially, of innovation and creativity. While noting that evidence is still thin, Temple (2000) argues that a growing number of works suggest that social capital is at least as important as education as a driver of economic growth. The relationship of social capital for the economic performance of nations was recognized by Olson (1982) and North (1990), in broad descriptions of the process of development, and was framed explicitly in terms of social capital by Putman (1993). Bruton (1998:904) wrote: “There is increasing doubt that growth is as simple as it appears in [simple] arguments, and renewed emphasis is being placed on more basic characteristics of an economy, especially entrepreneurship, institutions, and knowledge accumulation and application." The next question is to find out what are the determinants of social capital. Glaeser (2000) suggests that education is strongly associated with social capital, which indicates that an important component of policies aimed at increasing social capital necessarily needs to go hand in hand with policies aimed at increasing the educational level.

The above analysis was been driven by the perception that the development of post-graduation education on **Engineering Policy and Management of Technology** should **not** be unique to well developed countries and regions, but should also applies to Portugal and other late industrialized countries. One other important dimension of the knowledge economy that must be considered in the analysis includes the activities expressly oriented towards the **generation and diffusion of knowledge**. It is, as with education, risky to reduce a complex set of activities to a single educator, but the national *effort on research and development* provides an indication of the commitment, at the country level, to activities explicitly oriented towards the generation of new knowledge. These activities tend to occur in institutions, such as universities and research labs, or within institutional settings, such as the R&D unit within a firm, that provide incentives that foster the specialization on exploration and discovery, as well as exchange of knowledge.

Figure 2 shows the *scale* and the *intensity* of national expenditures on R&D for several OECD countries. The horizontal axis represents the scale of the expenditure on a logarithmic scale. The relationship between scale and intensity shows *decreasing returns*: as the scale of the investment grows, the increase in intensity also grows but at a logarithmically decreasing rate. The results also suggest that there are three different "paths" in which this relationship is expressed.

The thick line in represents a simple fitting of the position of most countries. Nordic countries have a path of their own, with a much more intense response to increases in scale. Portugal is shown in the lower left-hand corner of the figure, part of a line that includes other Southern European countries. Ireland is a particularly interesting example, since the scale of R&D expenditure is almost the same as for Portugal, but the intensity for Ireland is comparatively much higher. The large intensity of R&D expenditures in Ireland is largely due the R&D performed in the business sector, which in 1997 accounted for almost ¾ of the total R&D expenditure in Ireland (the share of R&D expenditure in Portugal was 22.4%). Ireland showed the largest increase in business R&D expenditure of all OECD countries in the 1990s, at an annual growth rate of close to 20%. However, most of this growth is being driven by foreign affiliates doing business in Ireland. The share of foreign affiliates in manufacturing R&D in Ireland in 1995 was close to 70%. This large share indicates a very low capacity of domestic firms to innovate. Ireland is an exception in this regard, since for most OECD countries domestic firms take the largest share of R&D performed in the business sector.

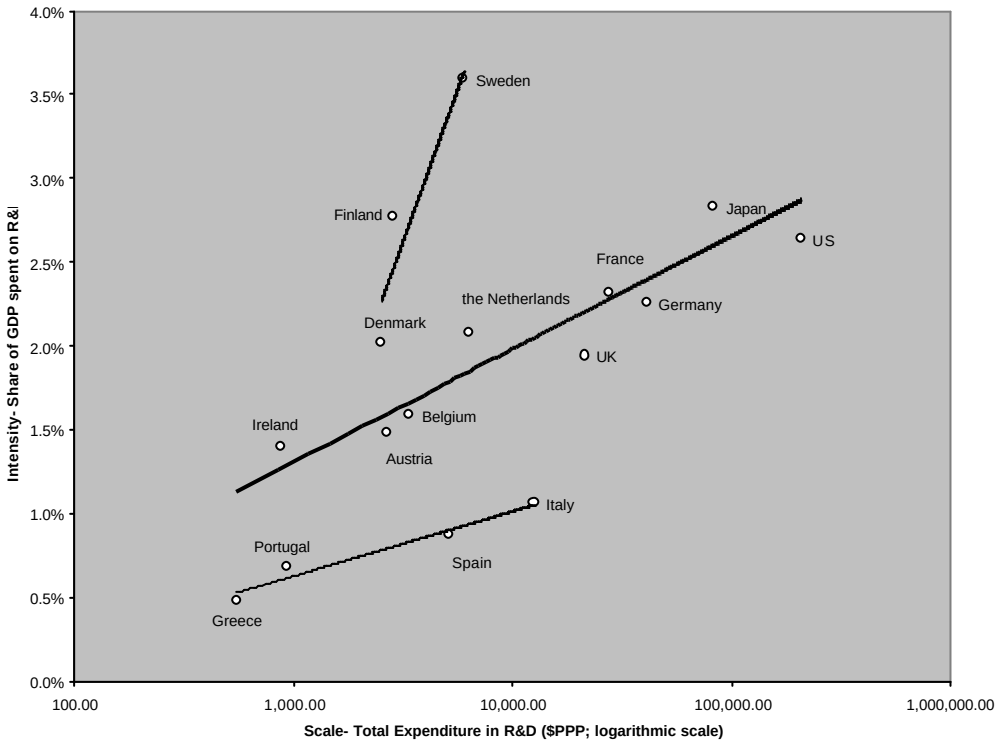

Figure 2- Intensity and Scale of R&D Expenditure in the OECD (OECD, 1997).

As with indicators of the intensity of usage of information and communication technologies, while the levels of R&D intensity in Portugal are low, the growth has been high. Portugal showed the one of the **largest increases on R&D gross domestic expenditure of all OECD** countries from 1995 to 1997. During this two-year period, R&D expenditure grew 9.4% in Portugal, while in the OECD as a whole it grew 4.5%. This growth represented a recovery from the slowdown of 1991-1995, when the Portuguese R&D expenditure grew only 3.8%. From 1985 to 1990 it grew 14%. Portugal also led the OECD in the increases of the **state incentives for private firms** to perform R&D, and has now the third strongest tax incentive in the OECD, after Spain and Canada.

R&D expenditure is an important indication of the commitment and resources a country devotes to knowledge production and diffusion, but the growing importance of knowledge extends beyond those activities traditionally associated with creativity and learning. Innovation performance, in particular, depends on conditions that foster **technology-based entrepreneurship**. Mechanisms such as venture capital and high growth start-up stock markets (like the NASDAQ) are ways to mobilize private capital for investment in knowledge economies (Soete, 2000). Gomper and Lerner (1999) show that venture-capital backed start-ups appear to have a disproportionate positive impact on innovation. In terms of venture capital, Portugal was the only OECD country that registered a negative annual growth rate in investments of this sort in 1997, according to the European Venture Capital Association, Conceição and Heitor (2000).

To conclude we argue that Portugal is facing the growing importance of digital technologies and of knowledge by accelerating the adoption of information and digital technologies. Structural debilities in the education and R&D system still persist, despite the recent growth of R&D expenditures and the effort to provide incentives for private spending on R&D. The challenges facing the Portuguese society clearly require the development of new skills, certainly including new competencies on technology policy and management and an “elite” of graduated engineers with policy skills. The question, which we must also consider, is the *institutional framework* necessary for their development.

2.3 Institutional Developments: Regulatory Systems, Role of the State and Social Dynamics

The OECD has called to our attention the fact that the factors driving and being driven by social change are both wide-ranging and deep. They include the diffusion of information technology, the growth of the knowledge economy, the globalisation of markets and radical managerial innovations. They constitute a tide of pervasive transformation that is simultaneously washing away and reshaping the social foundations provided by cultural traditions, social symbols and institutions of authority and security. From the family and school to the firm and parliamentary fora, long-standing social reference points are being called into question, reformed and reinvented. Exploring the challenges posed by this transition to new, more dynamic social foundations are critical to promote innovation for Portugal, as in most late-industrialized countries.

In this context, Petit and Soete (2000) provide insights into the impact of globalization and technical change on social cohesion and exclusion in the European Union. The most important relate to the fields of the *regulatory system* (they argue that the European policy makers are taking the lead in setting up appropriate frameworks in emerging science-based industries), *science and technology policy* (where user-learning could be more central), *territorial policy* (where the notion of knowledge capital could be much more central in the Structural Funds), and *labour market policy* (they propose a twin strategy of targeting small sectors with relatively large spillovers and boosting jobs in areas such as personal services).

Much can be learned by comparing the regulatory framework among OECD countries, mainly because in the past two decades an increasing number of countries have been reforming their regulatory environments in both the labor and product markets. It should be noted that regulation is essentially aimed at improving the functioning of market economies, by establishing the "rules of game" in areas such as market competition, business conduct, labor market, consumer protection, public safety and health, and the environment. In this context, many national reforms have been driven by comparisons with policies implemented and results obtained by other countries. In addition, cross-country comparisons allow identifying and analyzing to what extent regulatory arrangements and their economic implications are country-specific or apply more generally.

Figure 3 shows sample results collected in OECD countries making use of formal economic (i.e., constraints and incentive mechanisms concerning market access, the use of inputs, output choices, pricing, and incremental trade and investment) and administrative regulations (i.e., interface between government agencies and economic agents) that affect product markets, but ignore other important regulatory areas, such as environmental, health and safety. In addition, provisions concerning financial markets and land-use, which are likely to affect entrepreneurship, are not considered. The analysis does not assess the overall quality of regulations. It focuses exclusively on their relative regulations to market mechanisms in terms of the impact on the intensity of product market competition. Although it is clear that a market-oriented and administrative regulatory environment is only a necessary condition for enhancing product market competition, the analysis is particularly important to extract lessons for Portugal, namely in terms of the apparent relationship established between *product market regulations* and *employment protection*.

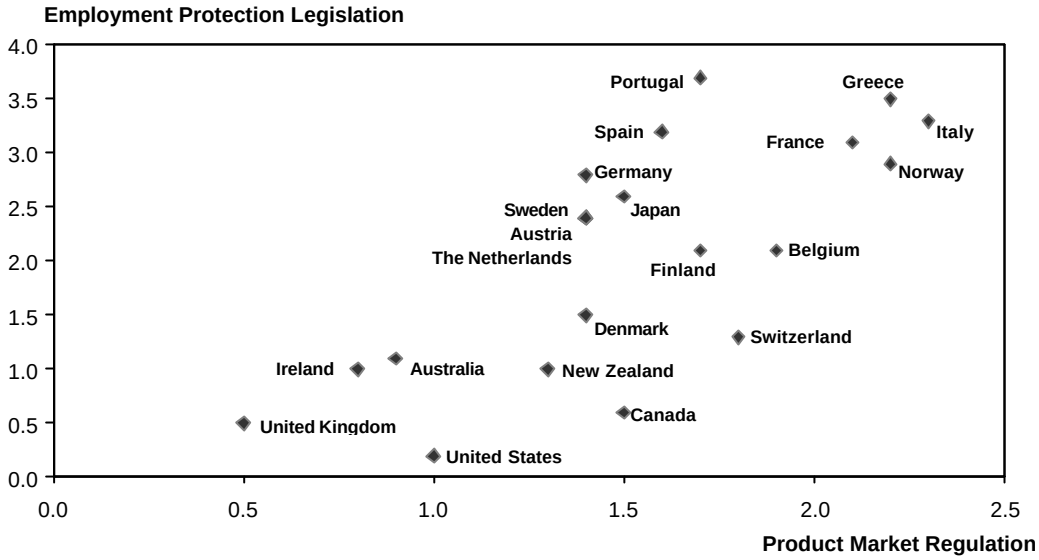

Figure 3 Product Market Regulation and Employment Protection Legislation in OECD
Source: Nicoletti, Scarpetta and Boylaud (2000); OECD – ECO/WKP(99)18

The evidence from the Figure 3 is that restrictive product market regulations are matched by analogous employment protection legislation restrictions to generate a **tight overall regulatory environment** for firms in their product market as well as in the allocation of labor inputs. In addition, the analysis suggests the possible existence of compounded effects on labor market outcomes, making regulatory reform in one market less effective than simultaneous reform in many markets. Making use of selected summary indicators for product market regulations (state control; barriers to entrepreneurship; and barriers to international trade and investment) and employment protection legislation (regular and temporary employment), Figure 3 identifies **three *clusters* of countries**:

- the US, UK and common-law countries characterized by a relatively liberal approach;
- continental European countries with relatively restrictive product market regulations; and
- Mediterranean countries characterized by a tight overall regulatory framework.

Based on a simple average of the summary indicators for regular and temporary contracts through factor analysis, the Mediterranean countries, and Portugal in particular, appear to have the tightest regulations. These data raise fundamental issues for European policies, certainly for Portugal, in terms of the economic effects as product market regulations and employment protections interact.

The question that thus arises is *how much does the impact of deregulation depend upon the broad socio-economic context and overall institutional framework?* For example, the strong regulatory framework of Norway, together with the *expected* high levels of *social capital* of the Nordic countries, at least as measured by the levels of "thrust", clearly result in a context which differ from that found in Mediterranean countries. Certainly "unemployment protection" for the former may represent a risk incentive, so that regulatory frameworks are not directly comparable. Anyway, there are a number of

implications for innovation, but in general the analysis calls for renewed attention to *deregulation,* which should definitely be accompanied by the development of new competencies and complementary actions at the levels of knowledge creation and diffusion.

The question of *regulation* must also be considered within a more complex and ambiguous tendency that is emerging at the outset of the 21st century, the perception that there is *a changing role for the state*. This is a controversial area, since it involves ideology and issues associated with personal beliefs about the effectiveness and fairness of social and political systems. In very broad terms, the changing role of the state can be characterized by an increased detachment from holding economic assets and from shying away from determining the direct allocation of economic resources. Yergin and Stanislaw (1998), in a popular book, framed this trend as a "battle" between the state and the marketplace, where the marketplace has been gaining further advantages.

In general, our argument is that the way new competencies -- in conventional engineering, economics and management -- may positively influence the development of a country and/or region depend on the institutional framework, which is currently particularly determined by regulation policies and the process of market liberalization. Again, this calls for the need to promote education and research in **Technology Policy** in engineering schools and related challenges are discussed below.

3. Challenges for Science and Technology Policy

Following the analysis of Conceição et al. (2001), it is clear that the US ability to generate knowledge only emerged with any significance almost one century after the industrial revolution that born in Europe. As Wright (1999) points out, for US development "what mattered most was the emergence in the nineteenth century of an indigenous American technological community, pursuing a learning trajectory to adapt European technologies to the American setting." The challenge before those that want to achieve a stage of *inclusive development* is to globally promote similar "learning trajectories". Beyond every single country, where local/regional based learning networks emerge, it is important to extend these learning networks and trajectories beyond a single country, so that they reach the entire Humanity.

These issues are too broad to be addressed in a context looking for specific policy suggestions. In the broadest sense, any discussion of these issues must include a treatment of the need for the promotion of democracy, peace, and the rule of law. These are the preconditions strongly emphasized by Conceição et al. (2001) as being essential in the case of the poorest countries. However, this discussion focuses on suggestions to be addressed in the context of science and technology policy.

3.1 The requirements for science and technology policy

Why the focus on science and technology policy? As emphasized earlier, learning can occur in many shapes and forms, some are informal, and others informal. The institutions and organizations that comprise the national and regional systems of science and technology attempt largely to formalize and accelerate the learning process for individuals, firms, and nations. By looking at this particular set of organization, their networks, and institutions, it should be possible to suggest routes for policy that can positively influence the conditions for inclusive development through learning.

The challenges for policy for moving towards inclusive development are really twofold. First, *what can be done* at the regional and national level *to start and sustain learning networks and trajectories* that can lead to development? Second, *how can the overall global learning processes be made more inclusive*, so that fewer countries are excluded, extending the reach of the learning networks globally?

At the national level, it is increasingly clear that innovation is not a direct consequence of R&D. The academic literature has repeated the lack of validity of the linear model of innovation *ad nausea*, but the fact remains that it still informs much of the policy rationale for investing in R&D. There is no question that the ideas that result from formalized knowledge exploration activities lead, in the long-run, to innovations, but to expect this result in the short run is misguided both for firms and governments. Kortum and Lerner (1998), for example, show that venture capital is probably much more effective in promoting innovation than R&D at the firm level.

This does not mean that firms and governments should stop doing R&D, but rather that they should do it for the right reasons. In terms of public policy, the realization that innovation and R&D are not as connected as once thought is particularly important. It means the firms may lack even more incentives to perform their own R&D as previously thought, and thus require a stronger intervention by the public sector. This may be particularly important for late industrializing countries, with scientific and technological systems not yet fully developed and matured. Often these countries, such as Portugal, show very low levels of private R&D, with disproportionate high government expenditures.

With the hindsight gained from the discussion of Conceição et al. (1998), it is possible to "explain" the increased need of public intervention for science and technology policies, as resulting from the *non-rival character of ideas*. Market mechanisms do not yield the allocation efficiency to be expected from competitive exchange. Expanding on the ideas proposed by Nelson (1996), Dasgupta and David (1994) suggest three ways to reach the conditions for the effective production of non-rival ideas. The first is **patronage**, consisting of a mechanism by which the government gives direct subsidies to producers of non-rival ideas, on the condition that it becomes publicly available at virtually zero cost after it has been produced. The competitive research grants awarded by many national Science and Technology Foundations are an example. The second, **procurement**, is based on direct production of goods by the government, awarding specific contracts to private agents whenever necessary. The case of State Labs in many countries illustrates this feature. Finally, the third, **property**, is associated with the privatization of the non-rival ideas, awarding producers monopolistic rights that yield returns

large enough to cover the total costs of production. Specific legal instruments include patents, copyrights, and trade secrets. Both patronage and procurement rely on a direct intervention of the government, by which the non-rival ideas remains non-excluded, and therefore effectively is a public good. Property grants private producers of new knowledge exclusive property rights in the use of their creations. This yields the private incentives in which markets operate efficiently. In the current political and economic context in which governments are increasingly called to reduce public expenses, the property mechanism may seem a suitable way to foster the development of new ideas.

The analysis suggests that it is crucial not only to make public resources available, but to do so *in a way* that provides the right incentives for S&T organizations *to hook up in learning networks* that can generate localized social capital and endogenous growth dynamics. That *way* is definitely *not unique* and depends on local conditions, roots and trajectories, which raise the question of *inclusive development*.

At the global level, growing trade liberalization and increasing reliance on information and communications technologies will certainly contribute to a wider and faster diffusion of knowledge, amplifying the reach of successful learning trajectories. Wolf et al (1999) show how financial flows from the US into Europe have helped to foster the launching of biotechnology start-ups in Europe. This is a typical example of the broadening of the scope of a learning network. Financial resources and management expertise from the US, coupled with public support for R&D and education in Europe, help to implement creative firms in Europe. Financial returns will go to the US, but human capital and knowledge will remain in Europe.

A critically overlooked aspect of enhanced knowledge flows around the world is associated with the free movement of people. Although possible in large regional contexts, such as the European Union, the US, Canada, and Mercosul, there are still major barriers to the movement of people, crucial bearers of knowledge.

Whether we are interested in enhancing local and regional learning networks, or globalizing the reach of successful learning networks, it is crucial to understand the local reality from different angles. The Comprehensive Development Framework, the World Bank strategy to guide its development policies for the 21st century includes papers that provide some of these more local perspectives in a context of globalization. Mostly from country-level studies, the papers give a perspective on relevant issues to move towards learning-based inclusive development. The report clearly identifies the forces of globalization and localization (World Bank, 2000):

> "*Globalization*, reflecting the integration of the world, will require the nation-state to reach out to international partners in order to manage changes affecting trade, financial flows, and the global environment; *localization*, reflecting the assertion of regional identities, will push the nation-state to reach down to regions and cities in order to manage changes affecting domestic politics and patterns of growth."

3.2 Challenges for Research

Balancing Innovation and Diffusion

Establishing intellectual property rights make ideas excludable, yielding to private incentives to production. This strategy is obviously implemented often in commercial computer ideas programs, books, and music CDs. However, there are two difficulties with this strategy. First, it is sometimes difficult to implement and enforce intellectual property rights, especially internationally, due to the ease of copying and reproducing ideas. Secondly, and most importantly, establishing property rights on ideas may have perverse effects, since if the benefits are given only to an inventor turned monopolist they may not spread society-wide.

In other words, too much emphasis may be being given to innovation at the expense of diffusion, which can slow the overall rate of technological change, or knowledge diffusion and adoption. To illustrate this, Nelson and Romer (1996) ask what would have happened if the concept behind a worksheet, first introduced by Lotus, would have been given exclusive rights? The competition between Lotus, Microsoft, and Borland (with their products Lotus 123, Excel, and QuattroPro) that entailed significant improvements in worksheets, might never have happened. Therefore, technology policy should not only focus on promoting innovation, which may restrict access to information so that innovative firms can accrue monopolistic temporary profits. Since diffusion is just as important, there is a need to promote measures that allow rapid distribution of knowledge. Ways to achieve this aim consist of continuing to channel public funds to R&D, giving incentives to the monopolistic firms to share their information sooner, and promoting networks.

Beyond the Excludable/Non-Excludable Dichotomy for *ideas*

The solutions described by Dasgupta and David (1994) for solving the allocation problem with ideas in a competitive market represent a significant advance over the early ideas of Nelson (1997). They acknowledge the possibility for private incentives to produce ideas, once this is made excludable through intellectual property rights, whereas Nelson, following most of the Solownian formulation of growth, viewed technology as a pure public good. Some new growth theories, as discussed by Conceicão et al. (1998), also take the view that private incentives can exist to produce ideas, once it is made excludable. Establishing intellectual property rights makes ideas excludable, creating private incentives for production. This may be appropriate when the ideas is, say, a new formula for Coca-Cola. The new ideas will benefit only one company. When the ideas under consideration has a potential society-wide impact, for example the cure for cancer, then this ideas production should be induced through patronage or procurement. It is in the public interest that the results be society wide available. This is the dichotomy between making ideas excludable or non-excludable. However, there is a large gray area, in which the decision to make ideas excludable may not be that easy. As Kyriakou (1997) has pointed out, some ideas may benefit neither a firm, nor the entire society. It can

benefit an industry, a region, a group of citizens, a number of countries. In this case, the incentives for collective action should be focused on the subjects affected. To subsidize through general taxation such an effort may not be justifiable. Kyriakou proposes a couple of instances that could generate focused mechanisms for collective action within the group of subjects that would benefit from the ideas. However, the field is wide open for innovative institutional settings that need to go beyond the pure public/private approach for giving incentives for ideas production.

Policies based on the Interactive Models of Innovation

The relation between science and technology in general, R&D in particular, and economic growth is widely acknowledged to be very complex, as this paper stresses. One way to structure this complexity is through the traditional linear models of innovation. In these models present successful commercialization of R&D as the result of a linear process beginning with scientific research, through development, financing, manufacturing, to marketing. They downplay connections between academia, business, and government.

From a conceptual point of view, the linear models have long been replaced. Today the relationships between technological innovation and economic wealth generation are understood as part of an integrated and interactive process that blends scientific, technological, social-economic and cultural aspects in rapidly moving environments. Myers and Rosenbloom (1996), expanding on the seminal work of Kline and Rosenberg (1986), argue that there are complex links and feedback relations between firms where innovation takes place, society in general, and the scientific system in particular. Innovation determines and is determined by the market. Organizational capabilities are seen as the foundations of competitive advantage in innovation and include firm-specific knowledge, communities of practice, and technology platforms.

Firm-specific knowledge represents the accumulated learning of the organization, which is pertinent to the business. This is to be distinguished from the body of generally accessible knowledge. The specific knowledge of a firm is embodied in the firm's workforce and its technology platforms, products and processes. Communities of practice are ensembles of skilled technical people with expertise on working across the organization. These communities span organizational divisions and provide both a repository for the firm's expertise and a medium for communication and application of new knowledge. Technology platforms are an output of the design process, which provide a framework on which families of specific products and services can be created over time. A platform comprises an ensemble of technologies configures in a system or subsystem that creates opportunities for a variety of outputs.

The fundamental message is that the complexity and interactively engagement of the different components of the innovation process at the firm level go much beyond the linear models of innovation. However, as David (1993) notes, we still have separate policies for research, education, innovation, industry, trade, and so on. A mix of policies, or **policy portfolio**, is needed in order to

make effective innovation policies, making justice to the complexity of the process. This may require inter-ministry (or inter-agency) projects, or even coordination at the top executive and legislative level, as the importance of the production, distribution, and usage of knowledge for growth and development becomes increasingly clear to public opinion.

Promoting wetware and ideas interaction

A particularly important policy area that needs to be integrated, according to the above framework, is education. As discussed by Conceição et al. (1998), *wetware*, also thought of as human capital, results from the natural endowments with which each person is born, and the accumulation of experience and education. Although formally a non-rival good, *ideas* may be useless without adequate levels of *wetware*, its production may even stagnate. This observation put into question the relevance of treating *wetware* as a purely private good or, as the new growth theorists say, a thing-like type of good. Depending on the importance of *wetware* to render specific types of ideas economically useful, *wetware* may be so closely linked with ideas that in itself it may acquire public good characteristics. Whether this is the case or not, the close linkage between ideas and *wetware*, revealed also in the learning processes as noted by Soete (1996), calls for a special attention for coordinating technology policy with educational policy.

Institutional development and renewal

Another important policy aspect that needs careful research is related with the extent to which *institutions* do matter in promoting and establishing socio-economic development. The process of liberalization -- including privatization, re-structuring and the introduction of competition --has become more and more marked internationally in the former state-owned network industries, especially in electricity and gas, but also in telecommunications, transport, water and waste management. These **critical infrastructures** determine to a great extent the design of our physical environment and our practical way of living, while providing a favorable climate for the development of a more service oriented economy. New technologies, and especially information and telecommunication technologies, have helped promote many changes, but liberalization also has had profound effects on the technologies used. The complex interactions between technology and institutions in shaping the technological trajectories of large technical systems may require the restructuring of industries, and this needs to be accompanied by clearer policies and legislation.

Another clear example of the need for new institutional developments is in the area *environmental protection*, namely in a context of sustainability, which requires integrated approaches over the entire life cycle of products. Policy measures that encourage the adoption of technologies and practices that are both sustainable and competitive have become an important source of innovation, requiring the correct design of institutions responsible for the interpretation, implementation, and enforcement of policy. Such measures employ systems-based analysis tools and seek to change the behavior of business and consumers, implying complexes and timely processes.

The Need for an Inclusive Development

Our last challenge refers to the problems posed by specific regional contexts, including late industrialized zones and developing countries. The emerging importance of knowledge has a potential for widening the gap between rich and poor within and between countries. An illustration of the potential for increasing inequality between countries can be found in Pritchett (1995), who shows the shares of return from human capital for different regions of the world. These vary from 0.26 to 0.62. This means that, assuming that the contribution for growth of total wages is 0.6, the contribution of human capital to growth is between 0.16 in Sub-Saharan Africa and 0.37 in the OECD.

However, not everything is bleak. *Ideas* are extremely cheap to transfer, and are subject to increasing returns and lock-in. Therefore even minor and rather inexpensive transfers of *ideas* through, say, an investment from a multinational corporation in a developing country, may have significant, expanding, and long-lasting effects. Romer (1996) advocated such an approach to economic development. Also, since the value of ideas is directly related to the scale of its market, expanding markets is also of interest to the holders of *ideas*. In some sense, the development of the knowledge-based economy is strongly inter-linked, calling for an *inclusive development*. The opportunities are huge, due to the cheapness of *ideas* and the advantages of expanding the markets, but there are also difficulties. *Wetware* is costly to transfer, and takes time. Nonetheless, as the World Bank (1997) suggests, the opportunities clearly out-balance the difficulties, and it is time to bring the developing countries to the community of the knowledge-based economies, in an inclusive manner.

4. Metrics for Knowledge

Beyond the specific topics for research and education, the challenge to ultimately consider in the development of an **Agenda in Technology Policy** is the acquisition and use of data. In fact, the availability of specific data showing the growing importance of knowledge is still scarce, as analyzed by Conceição et al (2000). Empirical advances have not accompanied the important theoretical advances in a better understanding of knowledge-based growth, much less the reality of the on-going processes of learning-based development. This is due to the characteristics of knowledge, which is extremely difficult to measure quantitatively. Howitt (1996) provides an excellent overview of the difficulties with the measurement of knowledge in the context of growth models. Knowledge is certainly not the only area where economics has measurement problems. Thus, Fogel (1999) claims that economics needs to catch-up with the economy, in the sense that much is happening that is unaccounted for and not understood at all. Specifically, he points out that “the root of the problem is the difficulty in measuring output in the service sector, which now represents two-thirds of the economy”. Moreover, the continuous proliferation of new services, and the processes of commodization, industrialisation and reorganisation of services on a global scale, suggest that services are at the core of current structural changes in modern economies.

Technology and innovation activities represent major forces behind such structural processes, with information and communication technologies playing a pivotal role in revolutionising the ways most of "traditional" services are produced, traded and delivered as well as offering opportunities for the generation of new ones in a variety of service industries. This already suggests that the old view according to which service industries are technologically backward could be misleading.

Until recently, the bulk of investment in scientific research and experimental development of the business sector has been carried out by manufacturing firms, but the picture is changing. Recent estimates show that in most industrialised countries service industries perform almost a fourth of total business R&D (25% in 1991 compared to 4% in 1981). In addition, with respect to the adoption and diffusion of new technologies, the service sector does not seem to be backward relatively to manufacturing. Service industries are heavy users of information technologies, and the bulk of information technology investment is actually used by services - around 80% in the UK and USA.

One problem with defining the stock of knowledge is that access to knowledge is limited. Another problem consists in separating economically useful from irrelevant knowledge, even though this distinction is extremely difficult in practice: some information may sit on the shelf for a long time until it becomes crucial for solving a problem, while other knowledge at the basis of a technological paradigm may suddenly become obsolete.

Economists used to solve the problem of measuring knowledge by looking at indicators of the rate of return on intellectual assets and using them to calculate the present value of intellectual capital, i.e. human capital. Such calculations imply a number of simplifying assumptions, including the definition of the depreciation rate. A more general methodological approach focuses on processes and flows rather than on states and stocks. This is basically the choice made in the calculation of science and technology indicators.

At present various indicators are used to illustrate the structure and the changes of the science and technology system and its impact on the economy and society: R&D, patents, innovation surveys, the technological balance of payments, trade of high-tech products, intangible investment, surveys on production technologies, the analysis of innovations, human resources, bibliometrics, the diffusion of information and communication technologies (Sirilli, 1997).

The analysis of intangible investment and innovation surveys shows that knowledge is deeply socially embedded in institutions and in the socio-economic environment in which they operate. The knowledge content of products and production processes is becoming more and more important, and investment is rapidly evolving towards the acquisition of services and the carrying out of activities that pay off over a long period of time. Intangible investment includes items such as: R&D, training of personnel, software, marketing, as well as goodwill, mineral exploration, development of

organizations, rights to use intellectual property or concessions. Taking the experience of Finland and the Netherlands, four components - research and development, education and training, software and marketing - make up about 80% of the total intangible investment which, in turn, represents between 20 and 50% of tangible investment. In Austria it has been calculated that intangible investment is 43% of all business investment.

Innovation surveys conducted in some thirty countries tell a similar story: half of the innovation expenditure of manufacturing firms is linked to the generation and acquisition of new knowledge through design, R&D, trial production, acquisition of know-how, training, marketing, the other half being spent for new machinery and equipment. Looking at the activities that are most often carried out for introducing new products and processes in service firms, the most frequent ones are R&D, development or acquisition of software, investment in machinery and training of personnel. The data from innovation surveys show also that innovation in firms is a diffused phenomenon, with about one third of firms introducing innovations over a three-year period (Sirilli and Evangelista, 1998).

The metrics for knowledge have to face at least three challenges. First, a comprehensive view encompassing many areas such as science, technology, knowledge, economic growth, employment, the environment, firm and social organization, education, institutions is more and more required. While no single model can yet cover such a vast territory, certainly a new cross-disciplinary understanding can create a better way to look at indicators and innovation systems. Second, national and local institutions and institutional cultures do matter and therefore indicators of these “intangible” aspects need to be devised. Third, the dimensions of knowledge (tacit and codified) as well as how the diffusion process takes place in competitive environments (markets) and in non-competitive settings (education, the health sector in countries where it is mostly public) need to be captured.

4.1 Measuring the Innovation Performance

How to measure the innovative performance of an entire country? Furthermore, *how to measure this performance in a way that is comparable across the diverse realities of many countries*? A joint effort of the OECD and the Eurostat has addressed these demanding challenges. They have promoted the development of innovation surveys at the country level according to criteria that value cross-country comparability of results. Portugal has been an integral part of this effort, which already has results for several European countries. This European effort goes under the name of Community Innovation Surveys (CIS), and its framework of inquiry has been adopted both in official and autonomous research surveys in many countries, from Eastern European countries to Latin America. By stressing cross-country comparability, the CIS loses some of its potential to probe into the dynamics of innovation within each country. It only asks broad generic questions, which normally have dissimilar meanings in different economies. However, it provides a reliable comparison of national innovation performance across countries.

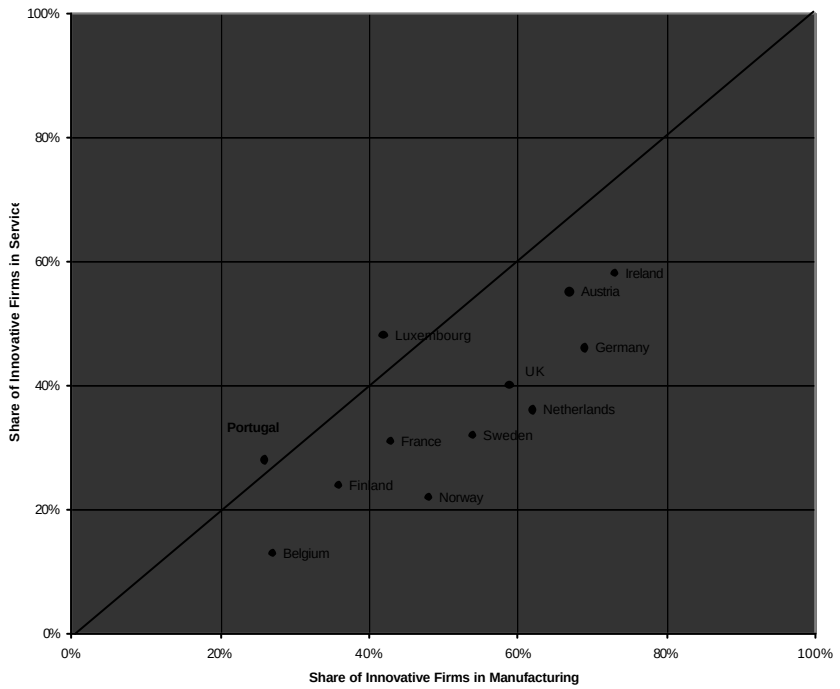

Figure 4- Cross-Country Comparisons of Innovation Performance in Europe
Source: Portuguese Observatory of Science and Technology

Figure 4 shows the overall innovation performance of European countries measured by the percent firms that have introduced innovations over a two-year period. The horizontal axis indicates the innovative performance in manufacturing, and the vertical axis in services. There is a close relationship between innovation in the services and in manufacturing, since countries are located along a 45-degree diagonal. In general, innovation rates are lower in services than in manufacturing.

Portugal appears towards the bottom of performance, being the least innovative country in manufacturing. However, Portugal innovates in services more than Belgium, Finland and Norway. Slightly more than a quarter of Portuguese manufacturing firms is innovative, while almost 30% of the service firms are innovative.

This simple result immediately raises important questions, namely: *Are Portuguese firms inherently less innovative than firms in other countries? If so, why?* Is the low innovation performance of Portuguese firms associated with low resources devoted to innovative activities by firms or by the government? If so, which type of resources (human, financial) should be increased, by what amount, and how should this increase be performed (R&D, training, public incentives)? Are the low national innovation numbers associated with the structure of the economy, in that Portugal has a predominance of firms that characteristically are associated with low innovative performance in every country? If so, how to enhance the growth of more innovative and technologically sophisticated firms in the country?

The first question needs to be analyzed in light of the threads of Portuguese culture, to determine whether national habits and history are innovation-unfriendly. It would be surprising to find that Portuguese citizens are inherently less creative or less entrepreneurial than others in different countries. If there are systematic differences at the firm level, the causes are more likely to be within the contextual framework that surrounds business activities in Portugal. This context is certainly influenced by culture (risk-aversion, tolerance of failure, level of confidence in the future), economic incentives (availability of finance, regulatory environment, competitive structure), and social features (depth and breadth of social contacts), among others.

Some clues to the second and third questions can be found in further empirical data concerning the resources invested in innovative activities and in R&D, which influence the innovative performance of a country. To explore the third question, it is useful to move from the country as a unit of analysis to a step below to explore the possible impact of structural economic factors on innovation by analyzing innovation across sectors.

The concept of *resources for innovation* is broadly understood in this section as the financial and human inputs that can contribute to further the innovative performance of national firms. Among these, it is natural to look first at the resources that firms themselves allocate to innovative activities. The analysis shows that more expenditure on innovation does not guarantee better innovation performance. For example, for manufacturing firms, Ireland and the UK spend almost the same on average, but Ireland's innovation performance is substantially higher. Sweden and Finland are the highest spenders, but are surpassed by many countries in terms of innovation performance.

While more expenditure is no assurance of a higher rate of innovation, it is also true that the countries with the lowest share of innovating firms are among those whose firms spend less on innovative

activities. Firms' expenditure on innovation activities is important, but equally relevant is the scale of overall national resources that are committed to science and technology. In fact, most *investments in science and technology create spillovers that benefit people and organizations beyond those that initiated the investment*. The analysis shows that two factors are important when considering R&D expenditure at the national level: the *total amount spent* (a measure of the scale of the investment) and the *resources allocated to R&D* as a share of the overall resources available to the country.

5. Building Systems of Innovation and Competence Building with inclusiveness

The analysis presented above considers a context in which the wealth and well being of individuals, organizations and nations is increasingly based on the *creation, dissemination, and use of knowledge*. This fact is reflected in the trend in developed economies towards an increasing investment in advanced technology, research and development, education, and culture. As a consequence, concepts such as *learning ability, creativity and sustainable flexibility* gain greater importance as guiding principles for the conduct of individuals, institutions, nations and regions. Against this background, and emphasizing concepts such as the *non-rivalry of information* and the *externalities* associated with education and research and development, this paper builds on the notion of **localized technological change** and the need to develop an agenda to promote the inclusive development. This is particularly appropriate for understanding the dynamics of innovation in much of Portuguese industry, which is heavily characterized by so-called "traditional sectors".

Although there is an emerging literature on technological innovation and industrial economics looking at the distinctive features and institutional characteristics of European regions (e.g. Wolfe and Gertler, 1999; Gambardella and Malerba, 1999), there have been few attempts to build analytical frameworks to improve understanding and to allow the development of well-sustained technology policies for less favored zones and late industrialized European regions, such as those of Portugal. In fact, the *neoclassical approaches in industrial economics* have emphasized the analysis of the microeconomic behavior of firms and built theories specialized in the American, and Anglo-Saxon systems and related market dynamics. On the other hand, *evolutionary economics* have attempted to improve our understanding of *learning* processes and the role of institutions in economic development, but have not specialized on the specific historical context of European regions, namely those characterized by late industrialization (e.g. Cooke and Morgan, 1998). Building on the evolutionary approaches and system theory, the concept of "*national system of innovation*" (e.g., Lundvall, 1992; Nelson, 1993; Edquist, 1997) has led to numerous studies of individual European countries. However, there is still a long way to go in order to assess the specificity of transition economies and late industrialized regions and countries, including Portugal.

The above heterogeneous approaches to technological innovation, all consider "**change**" at the center of the analysis. This has been considered throughout the entire paper, but taking into account that

firms´ competencies are characterized by *stability and inertia* and, therefore*, lock-ins and competence traps* are expected to occur, in that successful firms may be driven by their success in existing technologies to disregard new alternatives. Another important aspects to consider is that the phenomena of *increasing returns* and *path-dependence* affect the nature of the innovation processes and the dynamics of industries in Portugal and Europe.

Among the various aspects raised above, it should also be noted that the *sectoral specificity* in the organization of innovative activities, on one hand, and the *specific characteristics of local systems of innovation*, on the other hand, are expected to play a significant role in shaping the organization of innovative activity in Portugal. The prevalence of one effect over another depends on history and competitiveness of firms and their degree of internationalization.

5.1 On the dynamics of localized technological change

Following Antonelli and Calderini (1999), "the internal bottom-up learning process based upon the improvement of design and technological processes plays a major role in feeding the continual introduction of technological and organizational innovations". In this respect, these authors conclude *that technological knowledge is embedded in the specific circumstances in which the firm operate*, and *its generation is the result of a joint process of production, learning and communication*, of which R&D activities are only a part. In these terms, current evolutionary economics has shown the importance of path dependence of economic processes, in that it is at the core of selection mechanisms between competitive firms and technologies (Metcalfe, 1994). Competition is therefore the result of *the rate of change of market share*, apart from being dependent on differences in the rates of growth of individual firms. The result is a fully endogenous process, which, in the presence of increasing returns, gives rise to a strong interdependence between *specialization and diversification.*

The direct implication for innovation policies in Portugal is the important, but **limited role of demand** at the firm level in assessing the amount of incentives for firms to introduce technological innovations. In more general terms, the analyses call for the need to feed **all** the processes of learning ("formal" and "informal", as defined by Conceição and Heitor, 1999), implementing technological cooperation among firms and between firms and research institutions, and on-job-training of the workforce. Technological centers specifically designed to sustain localized processes of technological change might play an important role in this context. However, it is important to clearly emphasize the important **role of the science and technology system, S&T**, in fostering innovation, as well as the related implications for **public policy**.

5.2 Building a dynamic national science base

Following Pavitt (1998), "innovation studies confirm Tocqueville´s prediction that continuous technical change in business firms in modern society would require the development in close proximity of publicly funded basic research and associated training". In this context, analysis has shown that the main practical benefits of academic-based research are not "easily transmissible information", but involve the transmission of tacit and non-codifiable knowledge, with tendency for geographically localized benefits (e.g. Katz, 1994). Furthermore, following Hicks (1995), countries and firms benefit academically and economically from basic research performed elsewhere **only** if they belong to the international professional networks that exchange knowledge. This requires high quality foreign research training and a strong presence in basic research, mainly because *academic research is certainly not a "free good"*, although it has some attributes of a "public good". In this context, Pavitt, among others (e.g. Narin et al.,1997; Mowery and Rosenberg, 1998), conclude that "**public expenditure on academic research is a necessary investment in a modern country's capacity for technical change**".

To conclude this brief contextual analysis, one must consider the nature and extent of the influence of national patterns of technological change on the national science base. The analysis suggests the co-evolution of scientific performance with national technology and economy, in that "the rate and direction of the development of a country´s science base is strongly influenced by its level of economic development", Pavitt (1996).

Casual observations have however shown that patterns of scientific strength and weakness are strongly influenced by the nature of the societal and technological problems to be solved. Current understanding of the complexities of the knowledge bases that underlie future technological knowledge base is very limited, which led Pavitt (1998) to conclude that *"policies advocating more central management and choice based on foresight should be resisted. …The aim of policy should be to create a **broad and productive science base**, closely linked to higher (and particularly post-graduate) education, and looking outward both to applications and to developments in other parts of the world".* If any conclusion can be taken with direct application to Portugal, it is that the allocation of resources between broad fields of science should remain incremental, and that inadequacies in the rate of technological change should not be charged to academic research. However, important questions remain to be solved, mainly in terms of the way academic governance influence the performance of basic research activities, and the linkages between basic and applied disciplines. In addition, the way the demands for knowledge influence research policies remain to be examined.

One important dimension of the knowledge economy includes the activities expressly oriented towards the **generation and diffusion of knowledge**. As with education, it is risky to reduce a complex set of activities to a single factor, but the national *effort on research and development* provides an indication of the commitment, at the country level, to activities explicitly oriented towards the generation of new

knowledge. These activities tend to occur in institutions, such as universities and research centers, or within institutional settings, such as the R&D unit within a firm, that provide incentives that foster the specialization on exploration and discovery, as well as exchange of knowledge. If it is unquestionable today the critical role of the national S&T systems, it is also clear that they do not by themselves represent a true measure of innovation, namely in socio-economic terms. This motivates a broader analysis and an attempt to relate current practices for the evaluation of S&T with innovation measurements and other social measures.

5.3. A Policy Exercise: Promoting Innovation for Portugal

Recent work within the framework of the OECD International Futures Program suggests two broad policy-related conclusions that apply not only to OECD countries in general but to a large extent also to Portugal. The first is that if one is to build on the opportunities offered by the considerable progress that has been made in key technological sectors, if one is to reap to the full the economic benefits of rapidly integrating markets and the emerging knowledge society; and if solutions are to be found to tackle the challenges of the management of such a rapidly changing world, then *innovative, creative societies* are needed. The second is that in achieving that higher degree of innovativeness and creativity, **policy will matter**. The way ahead does not necessarily mean less government, not less policy but -- certainly in some key areas -- different policy.

The reservation "in some key areas " is important. Just because we are headed into a rapidly changing world in the coming decades does not mean that we have to throw out all policies and make a completely fresh start. Indeed, some policies that have proved their worth in the past may well continue to do so in the future. However, in some policy areas at least incremental adjustments are called for, and in yet others radical new thinking is required. This provides, in fact, a simple but convenient framework for looking at the role of general policies in the future and their implications for innovation: policy continuity, policy reform, and policy breakthroughs.

In this context, we present below four main groups of **strategies** to be considered for Portugal, which, *per se*, reinforce the need to develop research and education in *Technology Policy and Management*:

- **Human capital for Innovation:** Substantial investments in human capital, mainly at the **basic and secondary levels**, will continue to be a main target if the skill and qualification requirements to promote and nurture innovation of are to be met. This will require imaginative **new ways of organizing education** and validating people's knowledge. Regarding the Higher Education System, we first propose that the **institutional integrity** of the university needs to be preserved. Universities are a special type of learning organization specialized in producing and diffusing knowledge in unique ways. Second, we propose that there is a need to promote a **diversity of organizational arrangements**, even at the higher education level. Important as universities are,

they are not enough to guarantee prosperity. Indeed, organizational diversity could be a major contributor to ensure the institutional integrity of the university. In addition, we conclude that the allocation of resources between broad fields of science should remain incremental. The aim of policy should be to create a **broad and productive science base.**

- **Institutional Renewal for Innovation:** The OECD evidence suggests the value of structural and regulatory reforms in supporting the development of innovative and creative societies and economic growth. Among dominant factors, we envisage the role of market liberalization, and market opening, including the privatization of *critical infrastructures*. The process is to be implemented together a comprehensive program of *organizational renewal*, namely at the State level, and so as to promote the establishment of cooperative agreements towards the establishment of *social capital*. Fiscal incentives for *network organizations* and a new regulatory framework for employment protection and market regulation should be attempted.
- **Networking and Corporate strategies for Innovation:** A framework for devising and implementing strategies in business environments typical of transitional economies, such as Portugal, is to be considered taking into account **clustering effects**. The low level of "thrust" typical of the Portuguese society is a major barrier, that is to be overcome along the enterprise chain value and making use of aggressive *"product development strategies"*, together with specific factors as: Time to market; Market and Technology; Product and Process Innovation; Increasing returns markets; Managing environmental complexity; Managing organizational change; Devising knowledge strategies.
- **Alternative forms of financing Innovation:** Different funding forms should be used in Portugal, including offset and countertrade tools, in order to promote and develop different approaches to innovation within national companies. Traditional means of financing innovation tend to be "outdated" in the "new" economy context. Although national security is not a priority, activities such coast inspection, citizen protection and rescue and humanitarian programs, are examples of the existing needs for the country and, at the same time, opportunities for the use of offsets to foster economic development. Beyond offsets in processes for buying military equipment, countertrade should also be considered for the purchase of civil goods and *critical infrastructures,* such as the new Lisbon international airport. The research carried out aims to launch guidelines for the benefits for the Portuguese economy of the innovative use of offset and countertrade to increment new forms of cooperation between existing firms and new technology based firms creating multi-polar, interdisciplinary and market driven networks.

6. Summary

Based on the conceptualization of the *learning economy* and the related need to promote *systems of innovation and competence building*, the performance of knowledge-rich competitive environments depend on the **quality of human resources** (their skills, competencies, education level, learning capability) and on the activities and incentives that are oriented towards the **generation and diffusion**

of knowledge. In the context of globalization, we argue that the development of **university agendas on engineering policy and management of technology** has become critical for the successful use of engineering, science and technology to promote innovation.

In this regard the Portuguese situation is clearly deficient in absolute values, although much influenced by a *dynamic of change* and requiring a necessary *balance between the creation and diffusion of knowledge*. The challenges facing Portuguese society require the development of new skills, certainly including new competencies in *technology policy and management* and an "elite" of graduate engineers with policy skills. In general, the argument is that the ways new competencies, in conventional engineering, economics and management, may positively influence the development of a country and/or region depend on the institutional framework, which is currently particularly determined by regulation policies and the process of market liberalization. There is, finally, the need to promote education and research in *technology policy* in engineering schools.

Related challenges are presented and discussed in the context of the emerging importance of learning for development, including: i) balancing innovation and diffusion; ii) beyond the excludability of ideas; iii) deepen the conceptual framework established through the interactive model of innovation, making use of policy measures; iv) promoting wetware and ideas interaction; v) developing institutional frameworks; and vi) the need for the inclusive development. These challenges shape an improved **university agenda on technology policy and innovation**, supported by the experience in developing post-graduate education in *engineering policy and management of technology* at the *Instituto Superior Tecnico* of the *Technical University of Lisbon*, as described in http://in3.dem.ist.utl.pt/.

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