Portugal at the crossroads of change, facing the shock of the new: People, knowledge and ideas fostering the social fabric to facilitate the concentration of knowledge integrated communities

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ABSTRACT

Portugal has recently achieved the average OECD level in terms of the number of researchers per thousand workforce and the need to continue fostering the advanced training of human resources and the concentration of knowledge integrated communities as drivers of larger communities of users is discussed in the context of changing and evolving patterns in Portugal. This requires an ongoing public effort, but also a better understanding of the effectiveness of the mix of public support mechanisms and private incentives for the development of knowledge networks and flows of skilled people in times of increased uncertainty.

Our hypothesis gains from the experience of a unique set of international collaborations with leading institutions worldwide that has been successfully developed over the last years based on thematic R&D networks, integrating advanced training initiatives and programs of industrial affiliation. It is in this context that we frame our hypothesis and argue for the need for Portugal to continue attracting and fostering open and dynamic “creative communities”.

The main policy implication of our analysis is that Portugal needs to double the number of researchers per thousand workforce in the coming years. This requires a broad social basis for science policies across a wide range of public and private sectors, as well as that innovation is considered together with competence building and the need to foster individual skills through the complex interaction between formal and informal qualifications. Emerging user-centered innovation requires users able to access new knowledge. This implies a broad societal engagement in knowledge activities, including higher education enrolment, and we need to strengthen the top of the research system in order to create a locus of knowledge production at the highest level. But it also implies consideration of the social shaping of technology, because incentives and infrastructures do not operate in a vacuum, but shape and are shaped by the particular context in which they operate. Strengthening external societal links and “system linkages” is critical in making the institutional changes required to meet the needs of global competition and the knowledge economy.

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1. Introduction

This paper focuses on the challenges that specific world regions and small countries, like Portugal, are facing in their experience of international knowledge networks. It is factual and presented in the context of the emerging debate worldwide on patterns of innovation [1] and the need for long-term growth strategies. The analysis requires us to look at competence building and the need

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to better understand the evolving phenomenon of “democratizing innovation” [2]; we argue that value creation requires a serious commitment to the advanced training of human resources [3] and to supporting and promoting their research (basic and translational) through knowledge networks.

This is because Portugal has recently achieved the OECD average in terms of the number of researchers per thousand workforce (i.e., about 7.2 in 2008, although this is still low compared to the United States and Japan) and it has become a commonplace that “knowledge is increasingly important”. Commonplaces are comforting, but often sterile, both intellectually and in terms of suggesting actions to private and public decision-makers, given that it is difficult to add much novelty to discussions associated with commonplaces [4].

Some forty years after John Ziman launched a discussion on public knowledge [5] and thirty years after his work on reliable knowledge [6], to appreciate the significance of scientific knowledge we must understand the nature of science as a complex whole. In real science [7], we are reminded that “science is social”, meaning “the whole network of social and epistemic practices where scientific beliefs actually emerge and is sustained”. The practical implication is that we need to maintain the expansion of the social basis for scientific and technological development. This demands strong convictions not only from the scientific and technical professions and from public and private research organizations, but also from students and from the general population.

The rich history of past investments and current division of labor, or specialization, cannot be replicated in systems of smaller scale and less complexity. The key elements of the American history are those of diversity of policies and increasing institutional specialization and of the clarification of the unique roles of private and public incentives to support science and technology (S&T).

We must take up the challenge of probing deeper into the relationships between knowledge and the development of our societies. Our inspiration comes from, among others, the seminal work of Lundvall and Johnson [9], who challenge the commonplace by introducing the simple, but powerful, idea of learning. Lundvall and Johnson speak of a “learning economy”, not of a “knowledge economy”. The fundamental difference is to do with a dynamic perspective. In their view, some knowledge does indeed become more important, but some also becomes less important. There is both knowledge creation and knowledge destruction. By forcing us to look at the process, rather than the mere accumulation of knowledge, they add a dimension that makes the discussion more complex and more uncertain, but also more interesting and intellectually fertile.

The richness of the concept of the learning economy has been demonstrated in recent years throughout the world, by both leading scholars and policy makers. It has been recently addressed beyond Europe and it is at the center of the debate in China, India and Brazil. For example, MGK Menon, former Indian Minister of S&T and Member of Parliament and current President of the India International Center in New Delhi, has recently written about the conditions necessary for innovation to thrive, which require specific local action through a process of communization.

This closely follows the lessons Eric von Hippel, a well-known professor at MIT, has provided in recent years based on the American experience that user-centered innovation is a powerful and general phenomenon. It is based on the fact that users of products and services — both firms and individual consumers — are increasingly able to innovate for themselves. It is clear that this is growing rapidly due to continuing advances in computing and communication technologies and is becoming both an important rival to and an important feedstock for manufacturer-centered innovation in many fields.

Eric von Hippel has also shown that the trend toward democratization of innovation applies to information products such as software and also to physical products, and is being driven by two related technical trends: first, the steadily improving design capabilities (i.e., innovation toolkits) that advances in computer hardware and software give to users; and second, the steadily improving ability of individual users to combine and coordinate their innovation-related efforts via new communication media such as the Internet.

In other words, beyond suitable technical infrastructure, the process of democratization of innovation requires people with the ability to engage in knowledge-based environments. It is about people and knowledge, and this constant interaction has gained particular importance in recent years.

It is clear that the emerging patterns of innovation require new perspectives for public policies, which in many countries have in the past relied on supporting manufacturers and their intellectual property. Certainly we need to move on from those days and consider better ways to integrate policies, as well as to diversify across Europe.

This paper is divided in five sections, as follows. The next section shows the recent impressive progress Portugal has made in knowledge-related indicators, especially since the second half of the 1990s, as well as the country’s relatively low commitment to the knowledge economy some 20 years ago. We quantify the evolution of people, knowledge and ideas and argue for the need to understand the complex interactions between knowledge and society. This leads us on to discuss in Section 3 the structure of incentives within the European context and to show its differences from the US system, which is often taken as a world reference. Section 4 addresses the institutional context, focusing on higher education and the structural reform undertaken in Portugal in recent years. Our final discussion and conclusions are presented in Section 5.

2. The context to foster people, knowledge and ideas

The current emerging discussion on the role of knowledge and innovation should be understood in the context of the social and economic changes in Portugal within the European Union. This is quantified in terms of the changes in people, knowledge production and the diffusion of ideas, focusing on the evolution from a period based on investment to a stage based on innovation.
2.1. Methodological background

Bearing in mind the concept of the knowledge-based economy, it can be said that performance in competitive knowledge environments depends basically on the quality of human resources (namely their specializations, skills, educational level, and learning capacity) and on activities and incentives which are oriented towards knowledge creation and diffusion.

This analysis is framed conceptually in a systemic view of the role of knowledge, in which the main issue concerns knowledge sharing and diffusion. Therefore, the analysis focuses on the understanding of a complex national context, considering the following factors:

- **People**: This refers to the country’s human capital, in particular to the levels of formal education achieved by its workforce. Portugal has a dual society, in which most of the mature workforce has low educational and training levels, contrasting with a younger population with similar qualifications levels to those in other OECD countries. This has resulted in new challenges for developing the workforce’s qualifications development, and attracting new talents to science and technology in order to foster scientific employment and expand national and international knowledge networks.

- **Knowledge**: This is linked to the creation of new knowledge in Portugal, because the country had serious deficits in the scale and intensity of its R&D in the recent past in comparison with other OECD countries.

- **Ideas**: This refers to knowledge diffusion and therefore to the innovative capacity to which the relationship of firms with R&D centers brings new challenges, and also increasing accountability of its activities.

In order to complete the analysis, other aspects are discussed that are considered in our conceptual framework, such as:

- **Incentives**: consisting of necessary conditions, especially in terms of the public and private efforts that are vital to develop new and disseminate existing knowledge. In this context, market conditions, competitive structures and naturally, of course, public policies are considered, especially those associated with R&D and higher education funding.

- **Institutions**: consisting of sufficient conditions for scientific development and the success of a system able to foster sustainable strengthening of scientific institutions, as well as an appropriate legal and institutional framework for higher education at international reference levels.

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**Fig. 1.** Variations in the number of total researchers (FTE) per thousand working population for the period 2005–2007.
In this discussion we avoid the issue of infrastructure, in terms of the necessary conditions for the development of science, the functioning of scientific institutions and their relationship with society and firms in particular. The paper discusses the structure of incentives by looking at Europe and the US as a whole and identifying relevant differences between them. In addition, institutions are discussed in the particular context of higher education and the related major reform undertaken in Portugal in recent years.

2.2. People

The number of researchers in Portugal has recently achieved the average OECD level in terms of the number of researchers per thousand workforce. It has reached, for the first time in 2008, about 7.2 per thousand workforce. It is thus nowadays similar (and even higher in some cases) to the levels of Spain, Ireland, Italy, Germany, the Netherlands, and the UK; Fig. 1 shows that in recent years Portugal had the second highest percentage growth rate in terms of the total number of researchers (measured in full time equivalent, FTE) per thousand workforce (about 34%), well above the European average (which only grew by 5.4% from 2003 to 2006), Spain (13%) and Ireland (7%).

Although the values given may have been associated (as clearly signaled by a reviewer) with an attempt by those responsible for R&D statistics in Portugal to bring the figures closer to reality by devoting more attention to statistical inputs from particular areas of business, the data also show that the increase in overall research personnel has been matched by a significant increase in the total R&D personnel in the business sector, which has increased by 111% between 2005 and 2007, and 164% between 2005 and 2008, from 4014 to 10,589 FTE (Fig. 2). Most strikingly, according to the Ministry of Foreign Affairs, in 2008 Portugal attracted over 500 highly qualified foreigners of more than 40 nationalities outside the European region, more than double the number in 2007. Of the total of 533 highly skilled foreigners pursuing their professions in Portugal in 2008, 88 were researchers, while 132 were academics and the remaining 313 were mostly business professionals, medical and paramedical practitioners, computing experts, electrical engineers, chemical specialists, legal specialists, liberal professionals, and other highly trained personnel.

The proportion of R&D personnel as a percentage of total employees varies significantly between OECD countries (Fig. 3) [10]. In 2005 Finland and Sweden had the highest number of people employed in R&D occupations, respectively 32 and 28 people per thousand employed. On the other hand Mexico had only 2 people employed in R&D per thousand employed, while Turkey had 4. Portugal and Poland also showed levels below 10.

Regional differences within countries are the largest in the Czech Republic and Austria, where, respectively, in the regions of Prague and Vienna there are more than 40 persons per thousand employed in R&D. In the case of Portugal, there were over 20 persons per thousand employed in Lisbon in R&D in 2007, more than twice the country average.

It should be noted that for 13 out of 17 countries taken into consideration by the OECD Regions at a Glance 2009, the capital region has the highest rate of employees in R&D, in most cases with values much higher than the country average. But concentration in the capital region of R&D personnel is also seen in countries showing less regional dispersion.

Fig. 2. Total R&D personnel in the business sector (full time equivalent, FTE, 1982 to 2008p). (p) provisional data.
Our analysis is based on the evidence that the skill level of the labor force determines a region’s ability to promote and use innovation. Two additional issues should be considered, i) the level of women’s participation in science; and ii) the number of students in tertiary education.

Regarding women in science, the latest available data show that Portugal has achieved a remarkably high rate of women researchers, particularly in academic research (Fig. 4), with their share of the total number of researchers increasing from about 41% in 1997 to 44% in 2007.

The number of students currently in tertiary education is important because it determines, in part, a region’s future competitiveness in terms of its ability to promote and use innovation. Taking students enrolled in tertiary education as a percentage of the total population in 2005 as an average of about 4% of the population was enrolled in tertiary educational programs in OECD countries. Portugal follows this average, but the figure varies significantly between countries (Fig. 5). South Korea had the highest percentage of students (more than 6%), followed by the United States and Finland.

In 20 out of 23 OECD countries, there is a positive correlation between a skilled labor force and the number of universities and students, showing that some regions are better equipped than others in terms of current and future stock of human capital, and for dealing with technological change.

Regional differences within countries were even larger than between countries. Portugal, together with the Netherlands, Ireland, the United Kingdom, Canada, and Japan, displayed narrow differences in tertiary enrolment rates. On the other hand, Sweden, the Czech Republic and Slovak Republic showed the largest internal differences in enrolment in tertiary education, ranging from over 10%, to close to zero. For the Czech Republic and the Slovak Republic and for most of the other countries taken into consideration, the region displaying the highest rate is the capital region.

It should be noted that over the ten years between the mid-1990s and the mid-2000s, the total student enrolment in higher education institutions worldwide nearly doubled. As a result, institutions are engaging in and moving towards new kinds of transnational partnerships and mergers. But in comparison to the United States, European universities must overcome a greater number of challenges in this competitive and global educational landscape. For instance, considerable differences exist between Europe and the United States in the type of student engaged in higher education and the level of performance of individual universities. European universities not only have a smaller proportion of students between the ages of 20 and 29 enrolled in tertiary education compared to the United States, but the US has significantly more universities ranked highly by the leading university ranking references. Additionally, differences in the strength of institutional leadership,
suggested by significantly fewer highly cited researchers at European institutions, and in autonomy, separate European and American universities.

It is obvious that the rise in qualification level of the young Portuguese population is associated with the fact that the Portuguese higher education system grew rapidly in the 1980s and 1990s and opened up to young people of all social classes, rising from 30,000 students in the 1960s, to nearly 400,000 students since the late 1990s. After a period of relative stagnation, the following figures quantify the current trend associated with the reform process described later in this paper:

- Total enrolment in tertiary education of 20-year-olds has increased by 10% over the last three years (2005–2008), reaching about 33% of this age-group (compared to 30% in 2005). In other words, one in three 20-year-olds in Portugal is enrolled in tertiary education. This is similar to the European average, although still lower than that for most industrialized regions. It has

resulted mainly from an increase in non-university higher education, which grew at a considerably higher rate than that of university education.

- Total enrolment in tertiary education of adults aged 30–34 has increased by about 20% over the last three years (2005–2008), reaching about 4.1% of the corresponding age-group (compared to 3.5% in 2005).
- The total number of graduates per year increased by about 19% over the period 2005–2007, with graduates in S&T rising in recent years to about 18 per thousand population aged 20–29 years (well above the EU average). At the same time, the number of new PhDs in science and engineering (S&E) per thousand population aged 25–34 increased to 0.42 in 2007, compared to only about 0.3 in 2001.

Fig. 6 quantifies annual changes in S&T higher education entrants, graduates and PhDs for 1993–2003 and clearly positions Portugal among countries that favor technical education. This is important, because according to recent findings, increases in the number of students in S&T fields appear to be correlated with increases in gross expenditure on S&T per inhabitant, whenever the annual average increase of gross expenditure on R&D (GERD) per inhabitant exceeds 3%.

Moreover, the need to foster public understanding of science and to improve scientific and technological culture in society at large is well accepted in Portugal as part of national science policy, in which schools and other institutions (particularly science centers and science museums) have an important role in stimulating curiosity and desire for scientific knowledge. The European report on “Benchmarking the promotion of RTD culture and Public Understanding of Science” [13] acknowledges the leading role of national programs such as Ciência Viva, implemented in Portugal since 1996.

Public funding for the promotion of scientific and technological culture has attained the indicative level of 5% of public S&T funding. The network of Ciência Viva Centers has been extended throughout the country, to a total of 18 Centers at present. Projects to reinforce experimental teaching of the sciences in primary and secondary schools and to promote scientific and technological culture are being implemented in close cooperation with schools and research centers, corresponding to approximately 14 million Euros of public funding in 2007–2008. In addition, the Ciência Viva holiday program, places secondary school students in research and higher education institutions, including, for the first time in 2008, an exchange between Portugal and Spain. This program has involved over 5800 secondary school students since 1997. Also, the public involvement of children
Fig. 6. Average annual change of S&T higher education entrants, graduates and PhDs for 1993–2003 (mean normalized regression coefficient).

Source: OECD (2006) [12].
and their families in summer activities in astronomy, biology, geology, and engineering has become routine under the scope of the Ciência Viva Centers.

Although these figures indicate clear progress, they also show that Portugal has a long way to go in an increasingly globalized society. Portuguese society shows dual characteristics concerning educational qualifications. There is an active workforce with low educational levels and a younger population with similar qualifications to countries with more developed economies. However, development in Portuguese educational structures is held back by high retention and school dropout rates in secondary education. Until a few years ago, Portugal had the highest premature school dropout rates in the European Union.
rate\(^1\) of the entire European Union. Premature integration into the labor market, with low qualification levels, makes this population very vulnerable in periods of economic stagnation or slowdown occurs.

2.3. Knowledge

We recognize that scientific progress is a source of development.\(^2\) Public resources invested under rigorous international assessment policies lead to new knowledge, better advanced training of new human resources for society, new ideas and processes, which increasingly result in innovation, modernization of institutions, improved quality of life, economic productivity and better employment.

Scientific output in Portugal has doubled since 2004, when measured in terms of the number of internationally referenced scientific publications. Fig. 7 quantifies the relative scientific competitiveness of OECD countries and shows that Portugal, with about 626 scientific publications per million population in 2008, is above the EU-27 average ratio between output (publications) and input (public expenditure on R&D). This indicates that Portugal’s science base is internationally competitive, although still lacking the critical mass necessary for the concentration of knowledge integrated communities.

The growth in Portugal’s scientific production is currently based on about 12,000 PhD. researchers working in academic R&D centers (measured in FTE), corresponding to an increase of 25% in the last two years and a doubling of the number of PhD. researchers since 2000. This strong growth has had clear results in terms of the impact and visibility of the Portuguese scientific community internationally.

It should also be noted that around 20% of all new PhDs awarded since 1990 have been awarded or recognized in Portugal in the last two years. In 2008, Portugal has reached the target of 1500 new PhDs a year (Fig. 8). The percentage of new PhDs awarded to women recently passed the 50% mark, the highest percentage ever. The number of new PhDs in S&E fields currently represents around half (47%) of the total, while in the early 1990s they accounted for only one third of all PhDs awarded (31% in 1991). This reveals the increasing capability of Portuguese universities in offering PhD programs, as well in international cooperation, but it also poses new challenges regarding the mechanisms that guarantee the quality of PhD programs, and the need to strengthen their internationalization and to establish international scientific research networks, in which PhD students can be essential links.

\(^1\) The premature dropout rate is of individuals from 18 to 24 years of age, who left school before completing secondary education (twelfth year of studies), per each 100 individuals from 18 to 24 years of age.

\(^2\) According to the Frascati Manual, 2002, R&D is defined as a “creative work undertaken on a systematic basis in order to increase the stock of knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications”.

![Fig. 9. Total R&D expenditure as percentage of GDP per country, 2007. Note: data refers to 2008, last available year. Source: Eurostat, MSTI 2009 (value for Portugal 2008 is provisional).](image-url)
The rise in PhD holders has been promoted in recent years, together with scientific employment, through a new program launched in 2007 to support contractual arrangements for researchers. Over 1200 new PhD researchers were contracted by summer 2009. It is expected that this will stimulate major changes in the academic community and facilitate the renewal of teaching and research staff. In addition, it is clear that the national and international mobility of new PhD holders, mainly within the European area and in the context of a need to promote the internationalization of research units, is particularly relevant in the current stage of development of the Portuguese S&T system.

The evolution documented in the previous paragraphs is the result of investments; Fig. 9 illustrates that in 2008 the total R&D expenditure in Portugal (1.5% of GDP, while 1.21% in 2007) surpassed that of Spain (1.22%) and that of Ireland (1.31%) in 2007. Portugal had the highest growth of any European country in terms of total R&D expenditure in the period 2005–2007 (about 46% as a percentage of GDP), well above the EU-15 average (only 1%), Spain (9%), and Ireland (5%).

Again, we should note that the values given may have been given a positive bias by the efforts of those processing R&D statistics in Portugal to bring the figures closer to reality. Nevertheless, this should not be considered as a methodological change but rather as an attempt to uncover hidden and/or underestimated R&D efforts within a stable methodology. In fact, the total public budget for R&D grew at 11% per year from 2004 to 2009, while it had grown at 10% a year from 1995 to 2002, among the highest figures in Europe. This is important, because analysis has shown that fostering and maintaining excellence of the knowledge infrastructure is the most effective way for public funding to provide and facilitate resources (including qualified human skills) to firms and to stimulate their own investment in S&T, as well as to foster the entrepreneurial environment for innovation [14].

In fact, the increase in public investment in R&D in recent years in Portugal is matched by a steep rise in companies’ investment in R&D. The businesses’ share of the gross expenditure on R&D (GERD) grew by 71% from 1995 to 2005, a figure unmatched in Europe, as described in Section 2.4. But it was only from 2005 onwards that business expenditure on R&D exceeded that of higher education institutions, with overall figures exceeding 1 billion Euros from 2007 onwards. These changes coincided with a review of the tax system for corporate R&D in 2005, in a way that has fostered business expenditure on R&D, as well the employment of research personnel in private corporations.

Regional differences within countries are even larger than between countries (Fig. 10). The United States, Sweden, Finland and Korea show the largest regional disparities in R&D intensity across their regions. For the United States, the state of Maryland devotes 5.8% of its GDP to R&D, while the state of Wyoming spends only 0.45%. Ireland, together with Greece, the Slovak Republic, Belgium and Portugal, displayed minor differences in R&D intensity between regions. It appears that countries in which R&D intensity is the highest are, on average, also those displaying the most internal disparities.

Fig. 10. Range of regional R&D intensity (research and development expenditure as a function of GDP) in OECD countries, 2005.

* Austria and France year 2004

Data for Denmark, Iceland, Japan, Mexico, New Zealand, Switzerland and Turkey are not available at the regional level.
But our focus is on the conditions that have fostered the concentration of knowledge integrated communities and, therefore, the localization of large R&D intensities (R&D expenditures as a percentage of GDP). While we continuously improve our understanding of knowledge-based economies and the processes that enable learning societies to be sustainable, analysis has systematically shown the combined and evolving role institutions play, together with that of incentives [15].

Over the last decade, science policy towards institutional development in Portugal has been based on two main pillars: i) strengthening and restructuring the network of research centers throughout the country (in universities and related private, non-for profit institutions) through a systematic international evaluation every three years, with direct impact on their funding levels, which has been consistently implemented in Portugal since 1996; and ii) promoting critical mass across all scientific disciplines by establishing a network of selected “Associated Laboratories” in the form of relatively large research consortia oriented towards thematic networks in a number of selected institutions after an international assessment. By 2007, the network of scientific institutions included 510 research centers (257 after the 1996 evaluation) and 25 Associated Laboratories (with the first three launched in 2001), with an overall level of institutional funding about 71 million Euros in 2007 (25 million Euros in 1999).

It is in this context that a revised approach to institutional development has recently been launched, with particular emphasis on institutional cooperation at national and international levels, as a way of encouraging scientific activity in networks that promote inter-institutional relations. As well as helping to overcome the effects of the limited size of some research units, developing such science-based networks is intended to encourage the creation and dissemination of new knowledge and stimulate scientific development in a climate of constant change and growing internationalization of the scientific base.

In this respect, one critically important and emerging institutional issue relates to the training of students and young scientists in order to provide them with core competencies that help them to become successful researchers and prepare them with the appropriate transferable skills for the job market outside research and academia [16].

In addition, recognizing scientific knowledge as a public good introduces the need to consider new policy dimensions in S&T policy that are designed and implemented in a way that fosters independent scientific institutions, for which the organization of transnational institutions may provide a useful framework. It is also in this context that major efforts have been undertaken to promote the internationalization of the Portuguese scientific community.

Casual observations show that patterns of scientific strength and weakness are strongly influenced by the nature of the societal and technological problems to be solved. In any case, current understanding of the complexities of the knowledge base that underlie future scientific and technological advances is very limited, which led Keith Pavitt to conclude many years ago that “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” [17].

Under this broad scope, the following actions deserve special mention:

- A strategic program of international partnerships in science, technology and higher education was initiated in 2006 and by September 2007 the first doctoral and advanced studies programs were officially launched, bringing together several Portuguese universities and leading universities worldwide, including MIT, Carnegie Mellon University and the University of Texas at Austin. Unprecedented in Portugal, these programs facilitated the creation in 2007 of effective thematic networks involving a large number of Portuguese institutions with the objective of stimulating their internationalization through advanced studies projects and sustainable schemes to stimulate new knowledge and exploit new ideas in collaboration with companies and internationally renowned institutions, as follows:

  - The MIT-Portugal Program, [http://www.mitportugal.org/](http://www.mitportugal.org/), launched on October 2006 in the field of “engineering systems”, attributing special emphasis to the complex processes associated with industrial production, sustainable energy, bio-engineering and transport systems, in which Portuguese and MIT faculty and researchers identified three main thematic areas for research and development in close cooperation with an industrial affiliation program. They include sustainable energy and transportation systems, stem cell engineering for novel therapies in regenerative medicine, and materials and design-inspired products with specific applications in electric mobility and new medical devices. Overall, the program involved over 340 master and doctorate students at the beginning of its third year in September 2009.

  - Through the joint program with MIT, cooperation with the Sloan School of Management was strengthened through an international MBA program, “Lisbon MBA”. This involves co-funding from seven major Portuguese companies and banks in a way that will stimulate new research and the quality of education in management sciences in Portugal.

  - The CMU-Portugal Program, [http://www.cmuportugal.org/](http://www.cmuportugal.org/), was launched in October 2006 with emphasis on information and communication technologies and involving dual professional masters and PhD programs by Portuguese institutions and Carnegie Mellon University. The areas covered include new generation networks, software engineering, cyber-physical systems for ambient intelligence, human-centric computing (including language technology), public policy and entrepreneurship research, and applied mathematics. Overall, the program involved about 170 master and doctorate students at the start of its third year in September 2009.

  - Under the University of Texas in Austin-Portugal program, a “Collaboratory for Emerging Technologies, CoLab” was launched in March 2007, [http://www.utaustinportugal.org/](http://www.utaustinportugal.org/), focusing on collaborative research in advanced interactive digital media and integrating advanced computing and applied mathematics. Overall, the program involved about 70 doctorate students at the start of its third year in September 2009.

  - Also under the joint collaboration with the University of Texas in Austin, a “University Technology Enterprise Network, UTEN” was established in 2007 and oriented towards international technology commercialization and the professionalization of university technology managers.
• The Harvard Medical School-Portugal Program on translational research and information, http://www.hmsportugal.org/, which has established a new collaborative framework, launched in May 2009, to foster translational and clinical research programs and the development of a new infrastructure for delivering medical information across academic institutions and to the general public.

• The launching of Portuguese–Spanish networks oriented towards new developments and applications of nanosciences, within a boarder framework associated with the establishment of the Iberian International Nanotechnology Laboratory (INL). This was created by an international treaty between Portugal and Spain signed at the end of 2006 and is under construction in Braga (northern Portugal). It is the first international research laboratory set up in the Iberian peninsula, and is expected to achieve a reputation as an international institution of excellence with around 200 researchers from all over the world and an annual operating budget of around 30 million Euros matched by a similar investment budget funded equally by both countries.

• Cooperation with the Fraunhofer Gesellschaft for the establishment in Portugal of the first Fraunhofer Institute in Europe outside Germany through the recently established Fraunhofer Portugal Research Association. This is an ambitious project focusing on emerging information and communication technologies, such as “Ambient Assisted Living”, to be complemented by the establishment of R&D consortia and cooperative projects involving several Portuguese institutions and Fraunhofer institutes in Germany.

Strengthening the internationalization of higher education and S&T is recognized as a way to stimulate the integration of national institutions in emerging scientific networks at an international level. In general, internationalization should be a full component of all higher education institutions, stimulating the mobility of students and academic staff and strengthening scientific and academic activities in networks.

Fig. 11. Variation of private R&D expenditure as percentage of GDP, 2005–2007.
Source: GPEARI/MCTES — Gabinete de Planeamento, Estratégia, Avaliação e Relações Internacionais/Ministério da Ciência, Tecnologia e Ensino Superior, Inquérito ao Potencial Científico e Tecnológico Nacional (IPCTN).
Projects of interest to Portuguese industry have been launched, and this synergy has been extended by industrial affiliation programs, especially in stem cell engineering for regenerative medicine, automotive engineering, low-energy systems (via the MIT-Portugal Program), telecommunications and information systems (via the CMU-Portugal and Fraunhofer-Portugal Programs) and interactive digital media (via the UT Austin-Portugal Program). A network of technology transfer offices to support the development and internationalization of technology-based entrepreneurial projects has also been developed under the scope of the University Technology Enterprise Network (UTEN).

2.4. Ideas

The above analysis indicates the need to give constant priority to people and knowledge in a way that promotes networks of institutions with the necessary critical mass capable of promoting the international standing of Portuguese scientific and tertiary education institutions. We now complement this vision by looking at the diffusion of ideas. Our analysis has emphasized the following:

- First, innovation must be considered together with competence building and advanced training in individual skills through the complex interactions between formal and informal qualifications. This requires a broadening of the social basis for knowledge activities, including higher education enrolment, and strengthening the top of the research system leading to knowledge production at the highest level;
- Second, strengthening experimentation in social networks necessarily involves flows of people. It is organized cooperation among networks of knowledge workers, together with different arrays of users that will help diffuse innovation. But establishing these innovation communities requires the systematic development of routines of collaboration on the basis of sophisticated research projects, as well as the design of products and services. This requires public policies to foster “brain circulation” between leading institutions worldwide.

In the following paragraphs we address these issues by looking at the evolution of three different and complementary measures namely: i) private expenditure on R&D, which measures the private efforts towards innovation undertaken, mainly by medium and large companies; ii) the capacity of Portuguese companies to successfully export knowledge services, which can be assessed through the technology balance of payments; and iii) emerging technology-based start-ups, using of a dedicated observation exercise.

Fig. 11 shows that Portugal experienced the highest growth rate in Europe in private R&D expenditure between 2005 and 2007, which practically doubled when measured as a percentage of GDP (97% increase). It reached 0.6% of GDP in 2007 and 0.8% of GDP in 2008, while it was only 0.3% of GDP in 2005.
technological capacity located in Portugal; (2) a university-research connection; (3) an intellectual property strategy (provisional or

Table 1 shows a series of technology-based SMEs and related business ventures selected using the following criteria: (1) a
carried out in Portugal over the last year by the University Technology Enterprise Network (UTEN). As a result of that assessment,
and the launching of technology-based start-ups. Bringing ideas to the market is their main goal.

2007, China and India’s share of global R&D personnel is projected to jump from 19% to 31%.

and Shanghai are competing for jobs that traditionally went to their counterparts in Europe and the US. For example, by the end of
companies or subsidiaries in countries like China, India and Brazil. Well-trained engineers and computer scientists from Bangalore

research groups. Others are going beyond their borders to procure products and services at lower prices, often from new
creation of start-ups

most dynamic regions in the world today in terms of growth and innovation, were propelled mainly by new technology and the

Fig. 13. Evolution of the Portuguese technological balance of payments (imports minus exports). Values in thousands of Euros.
Source: Banco de Portugal (Bank of Portugal), April 2009.

Fig. 12 shows that knowledge-intensive services, including financial services and insurance, computing services, and communications,
are the sectors with the highest investment in R&D, and simultaneously those with the highest growth between 2005 and 2007, along
with the energy sector (highest growth during that period) and the automotive industry. Private expenditure in the energy sector also
increased 80-fold, while communications registered a nine-fold, followed by financial services and insurance (seven-fold), the
automotive and computing services (both six-fold). Note that during the same period R&D investment in the food industry sector
increased 3.5 times and the pharmaceutical industry by only 1.5. On the other hand, R&D expenditure decreased during the period
2005–2007 for the electrical appliance and construction sectors, although with a relatively low absolute level overall. This is partly due
to methodological issues affecting the classification of companies in the various sectors listed and also to market-related adjustments
in these two sectors, which are particularly affected by the demand for construction (especially public infrastructure).

The trend shown in the above paragraphs can be further documented through the evolution of the technological balance of
payments (Fig. 13), which is positive since 2007 for the first time in Portugal. The technology balance of payments records commercial
transactions related to international technology and know-how transfers. It consists of money paid or received for the use of patents,
licenses, know-how, trademarks, patterns, designs, technical services (including technical assistance) and for industrial research and
development (R&D) carried out abroad. Unlike R&D expenditure, these are payments for production-ready technologies.

In the context of globalization, these transfers of disembodied technology, together with transfers of technology embodied in
products (trade) and in persons (migration), increased greatly during the 1990s for most OECD countries. Overall, the OECD area
has a surplus of more than 20 billion US dollars with the rest of the world. The United States is still the main net exporter of
disembodied technology in the OECD area. Since 1993, Japan has become a net exporter, while the European Union was a net
importer overall until the beginning of this century. Between 1995 and 2005, the European Union transformed its technology
balance of payments deficit into a surplus, although this includes intra-EU flows, while the US surplus shrank.

Only three EU countries have traditionally been net exporters of technology: Sweden, the Netherlands and Belgium. In 2005,
the main technology exporters as a percentage of GDP were Luxembourg, Sweden, the United Kingdom, Denmark, Belgium, the
United States, Japan, Finland, Canada, the Netherlands, Germany, France and Norway. The main importers were Ireland, Hungary,
New Zealand, the Czech Republic, Poland and Korea. Portugal has seen considerably changes in the flow of international transfers
of technology in recent years and in 2007 become a net exporter particularly of R&D services, which are the result of the
technological capability of Portuguese companies and their international impact worldwide.

To conclude our analysis, we now turn to science and technology-based entrepreneurship, which is increasingly seen as a key
element of a nation’s or a region’s ability to grow and prosper. Silicon Valley and Route 128 in the Boston–Cambridge area, the
most dynamic regions in the world today in terms of growth and innovation, were propelled mainly by new technology and the
creation of start-ups — Apple, HP, Google, and Intel, to name a few. At the same time, start-up companies are also becoming global
enterprises and engage in services, manufacturing, and research throughout the world, with strong links to universities and
research groups. Others are going beyond their borders to procure products and services at lower prices, often from new
companies or subsidiaries in countries like China, India and Brazil. Well-trained engineers and computer scientists from Bangalore
and Shanghai are competing for jobs that traditionally went to their counterparts in Europe and the US. For example, by the end of
2007, China and India’s share of global R&D personnel is projected to jump from 19% to 31%.

At the same time, research universities worldwide are attempting to foster a range of technology transfer offices and
commercialization activities, together with industrial liaison programs, mostly intended to foster entrepreneurial environments
and the launching of technology-based start-ups. Bringing ideas to the market is their main goal.

In this paper, we address this issue by looking at a thorough assessment on national inventors, entrepreneurs and companies
carried out in Portugal over the last year by the University Technology Enterprise Network (UTEN). As a result of that assessment,
Table 1 shows a series of technology-based SMEs and related business ventures selected using the following criteria: (1) a
technological capacity located in Portugal; (2) a university-research connection; (3) an intellectual property strategy (provisional or
approved patents, copyrights, trade secrets) associated with the venture; (4) an emerging venture, not necessarily mature; and (5) a clear commercialization interest and potential. A two-step assessment was performed for each company, including a “Rapid-Screen” assessment with specific criteria used to determine the technology’s readiness for commercialization, and a “Market-Look” that focused on eight to twelve interviews in the technology’s potential markets.

From analysis of the above sample it is clear that innovation is not a direct consequence of R&D, but is also clear that continuous public investment in R&D has been critical in training a large number of people over many years and in creating the necessary environment to foster new technology-based businesses. In the academic literature, the lack of validity of the linear model of innovation has been repeated ad nauseam, 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 lead, in the long run, to innovations, but to expect this to be the case in the short run is misguided for both firms and governments. Many authors, for example, have shown that venture capital is probably much more effective in promoting innovation that 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. And there are many, from promoting human capital, to extending the frontiers of knowledge. But in terms of public policy, the realization that innovation and R&D are not as connected as was thought is particularly important. This realization means that firms may lack even more incentives to perform their own R&D than previously thought, and thus require stronger intervention from the public sector, particularly in times of increased uncertainty in global markets. This may be particularly important for late industrializing countries such as Portugal, with scientific and technological systems that are not yet fully developed and mature. Often these countries show very low levels of private commitment to R&D, with disproportionately high government expenditures on R&D.

The notion that partnership is the solution to many current policy questions may no longer suffice. New skills requiring intense and effective direct contact between different institutional agencies are essential and increasingly utilized. Linkages between different parts of the system will now require assimilating, sharing, acquiring and creating knowledge. Firms seek for access to knowledge in labs and universities and research centers. Universities search for collaborations, contracts and agreements from businesses. University students are employed and trained by industry. Entrepreneurs, innovative agents, knowledge producers, researchers, academics, and students are connected in a process of knowledge producing and sharing.

The challenges for policy in order to move towards inclusive modern societies and wealth generation are really threefold. First, what can be done at the level of our science and education systems to provide the bridges across disciplines required to cope with the increased complexity of every-day issues? Second, what can be done at the regional and national level to establish and sustain learning networks and trajectories that can lead to wealth creation and the required entrepreneurial capacity allied to new scientific competences and training needs? Third, how can the overall learning process be made more inclusive, so that fewer regions and countries are excluded, extending the global reach of learning networks?

3. The structure of incentives: is European approach sustainable?

We now turn to an analysis of the structure of incentives for people, knowledge and ideas, as well as the social capabilities that enable the context in which knowledge networks develop. We will focus on a European perspective, because the challenges facing Portugal are, above all, those for Europe as a whole.

How far will Europe be able to strengthen a public funding policy for R&D that is oriented, focused, and consistent? This is particularly relevant when compared with the experience in the US, where public funding has been relatively focused and consistently oriented towards academic and basic research. Europe, in contrast, has had a diffuse and non-focused public funding policy that has attempted to fulfill a number of different objectives, and varying over time to accommodate circumstances and shifting priorities leading to inconsistent allocations over time. The recent successful launch of the European Research Council provides a new orientation and suggests that Europe needs to increase public funding of R&D that should be consistently allocated and oriented towards academic and basic research in a way that can stimulate the development of knowledge infrastructure. Fostering and maintaining the excellence of this knowledge infrastructure are the most effective ways for public funding of R&D to provide new opportunities for all citizens and to help provide the necessary resources (including qualified human skills) for firms to increase their own investment in S&T, as well as to promote the entrepreneurial environment necessary for innovation.

Fig. 14 shows that the EU15 has doubled its gross expenditure on R&D (GERD) over the last 25 years, but the gap in GERD between the US and the EU has widened, with gross American expenditure on R&D increasing by more than 2.3 times over the same period. At the same time, China has increased its GERD more than five-fold in the last decade. The strong economic performance of the US economy during the 1990s, along with the changes outlined above, has contributed to a general and widespread shift towards market-based, rather than publicly supported, incentives for S&T in most OECD countries, and especially in Europe. In fact, the conclusions of the European Union intergovernmental summit held in Lisbon in 2000 (the Lisbon Summit [18]) can be interpreted as a call for Europe to enact policies that, in part, seek to replicate and improve upon the innovation-based economic performance that has characterized US economic growth. But, overall, private spending on R&D in the EU15 has remained stable since 2000 at around 80 billion Euros and has not kept up with the equivalent American increase during the 1990s, as documented in Fig. 15. In addition, public spending in Europe has only slightly increased.

An examination of the sources of funding and expenditure on R&D in Europe and the United States offers some insight into the reasons for the challenges discussed above. The ratio of public expenditure to industry expenditure on R&D in Europe is low, but there has been a long and persistent downward trend in this ratio in both the EU and the United States. Despite the growth in the amount of funding from private sources in the United States, public expenditure on basic R&D has not gone away. Instead, it has increased since the mid-1990s, and continues to push private spending on basic R&D.
Table 1
Examples of technology-based (early stage and mature) SMEs formed by university alumni.

Source: University Technology Enterprise Network, UTEN Portugal.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Name</th>
<th>Founded</th>
<th>Location</th>
<th>Technology-based products or services</th>
<th>Links to R&amp;D Center/University</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agro/food</td>
<td>CookLab</td>
<td>2007</td>
<td>Lisbon (PT)</td>
<td>Molecular Gastronomy research, new food products development</td>
<td>Institute of Agronomy (ISA), Technical University of Lisbon</td>
</tr>
<tr>
<td></td>
<td>MicroPlant</td>
<td>2006</td>
<td>Gondomar (PT)</td>
<td>Microgourmet, Micogest, Micogrower</td>
<td>University of Minho</td>
</tr>
<tr>
<td></td>
<td>Natural Concepts – Biotronics</td>
<td>2007</td>
<td>Guimarães (PT)</td>
<td>Controlled production of extracts and fractions with antioxidant, anti-aging and neuroprotective activities, by in-house developed techniques</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prosense, Lda</td>
<td>2009</td>
<td>Lisbon (PT)</td>
<td>R&amp;D in Sensory analysis of food products</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Agri-Ciência, Consultores de Engenharia, Lda.</td>
<td>2000</td>
<td>Lisbon (PT)</td>
<td>Decision Support Systems for Knowledge and Information Management (Web-based business intelligence solutions)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bisalho SA</td>
<td>2005</td>
<td>Lisbon (PT)</td>
<td>Global Platform Screening for Drug Discovery (GPS D2) — drug discovery platform based on in vivo assays performed in humanized rats</td>
<td>ICAT-School of Sciences, University of Lisbon, laboratory facilities</td>
</tr>
<tr>
<td>Bio/pharma</td>
<td>Biopremier</td>
<td>2003</td>
<td>Lisbon (PT)</td>
<td>Diagnosis methods, molecular design (Agro-food, clinical)</td>
<td>ICAT-School of Sciences, University of Lisbon, laboratory facilities</td>
</tr>
<tr>
<td></td>
<td>NZYTech Lda</td>
<td>2008</td>
<td>Lisbon (PT)</td>
<td>Synthetic Genes, Recombinant Enzymes, Analytical and Diagnostic Test Kits and Molecular Biology Products</td>
<td>School of Veterinary Medicine, Technical University of Lisbon</td>
</tr>
<tr>
<td></td>
<td>Stemxnotes</td>
<td>2007</td>
<td>Guimarães (PT)</td>
<td>Bone/skin regenerative medicine</td>
<td>IST/Technical University of Lisbon</td>
</tr>
<tr>
<td></td>
<td>AlfaGAMMA</td>
<td>2002</td>
<td>Boston (US)/Lisbon (PT)</td>
<td>Carbon monoxide releasing molecules (CORMs)</td>
<td>IMM/University of Lisbon/IST/University of Porto</td>
</tr>
<tr>
<td></td>
<td>Bioskin Molecular and Cell Therapies</td>
<td>2002</td>
<td>Maia (PT)</td>
<td>Biomaterials and stem cell therapies</td>
<td>IST/Technical University of Lisbon</td>
</tr>
<tr>
<td></td>
<td>Biotec</td>
<td>1997</td>
<td>Lisbon (PT)/Durham (US)</td>
<td>Stem cells cryopreservation</td>
<td>IST/Technical University of Lisbon</td>
</tr>
<tr>
<td></td>
<td>Biotrend</td>
<td>2000</td>
<td>Lisbon (PT)</td>
<td>Anti-HER2, Anti-Hsp90, Cardiotrophin I, anti-PThPeP</td>
<td>IMM/University of Lisbon/IST/Technical University of Lisbon</td>
</tr>
<tr>
<td></td>
<td>Crioestaminal</td>
<td>2003</td>
<td>Cantanhede (PT)/SP/IT</td>
<td>Cryopreservation of stem cells</td>
<td>IST/Technical University of Lisbon</td>
</tr>
<tr>
<td></td>
<td>Cristoestan</td>
<td>2008</td>
<td>Porto (PT)</td>
<td>Mechanical or Electrostatic BiCyclone Systems for high Efficient Particle Capture</td>
<td>IMM/IO/ST/Biocant</td>
</tr>
<tr>
<td>Energy/ environment/sustainability</td>
<td>Albatroz Engineering</td>
<td>2006</td>
<td>Lisbon (PT)</td>
<td>Sensors, computers and avionics hardware and software embarked in vehicles to identify automatically and in real-time potential hazards for utility and transportation assets, with emphasis on power-lines</td>
<td>IST/Technical University of Lisbon</td>
</tr>
<tr>
<td></td>
<td>WSIP Electronics</td>
<td>2008</td>
<td>Coimbra (PT)</td>
<td>Energy Analyzer, Emissions Reporting, 3D Web-based service, Building Performance and Automation</td>
<td>University of Coimbra</td>
</tr>
<tr>
<td></td>
<td>WS-ENERGIA</td>
<td>2006</td>
<td>Oeiras (PT)</td>
<td>DoubleSun® Four and Five, Helios, Solar Trackers (WST1000/1600) Solar concentration technology which integrates precise tracking with 2 X-flat reflective optics</td>
<td>IST/Technical University of Lisbon</td>
</tr>
<tr>
<td>ICT/software/digital media</td>
<td>SRE</td>
<td>2003</td>
<td>Torres Vedras (PT)</td>
<td>Web Campaign Auditing, Web traffic Analysis, Browser Recon — browsers’ identification tool applied to web traffic analysis and auditing</td>
<td>IST/Technical University of Lisbon</td>
</tr>
<tr>
<td></td>
<td>Bullpharma</td>
<td>2008</td>
<td>Cascais (PT)</td>
<td>Web-platform Auction Arena</td>
<td>FEUP/University of Porto</td>
</tr>
<tr>
<td>Sector</td>
<td>Name</td>
<td>Founded</td>
<td>Location</td>
<td>Technology-based products or services</td>
<td>Links to R&amp;D Centre/University</td>
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</tr>
<tr>
<td>Medical/devices/</td>
<td>Biodesvices</td>
<td>2006</td>
<td>Aveiro (PT)</td>
<td>ITReport, CAPSview, BioDreams, VitalJacket, OphthalmSuite (Acquisition &amp; imageCORE), EyeDropper: Compliance Validation System, Medical Expert Diagnosis</td>
<td>University of Aveiro</td>
</tr>
<tr>
<td>diagnostics</td>
<td>Blueworks</td>
<td>2007</td>
<td>Coimbra (PT)</td>
<td></td>
<td>University of Coimbra</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Centro Câncer de Coimbra; NEURONET — Electromedicina e Psicofisiologia da Visão, Lda; ISA — Intelligent SensingAnywhere, S.A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IBRU/University of Coimbra</td>
</tr>
<tr>
<td></td>
<td>Critical Health</td>
<td>2008</td>
<td>Coimbra (PT)</td>
<td>Retmaker — automatic detection of lesions in the retina of diabetic patients suffering from diabetic retinopathy, HCV Genotype (amplifies viral nucleic acid extracted from patient’s plasma samples to determine the genotype); Detection of Hepatitis B virus genetic diversity (allows to investigate the genetic diversity of HBV in infected patients)</td>
<td>IMM/University of Lisbon</td>
</tr>
<tr>
<td></td>
<td>GenoMed</td>
<td>2004</td>
<td>Lisbon (PT)</td>
<td></td>
<td>IMM/University of Lisbon</td>
</tr>
<tr>
<td></td>
<td>iSurgical 3D</td>
<td>2009</td>
<td>Gualtarés (PT)</td>
<td>3DPictor System — System for automatic and personalized modelling/bending of surgical prosthesis for correction of pectus excavatum based on pre-surgical imaging information (CT Scan). This technology allows a more accurate surgical intervention</td>
<td>University of Minho</td>
</tr>
<tr>
<td></td>
<td>PETsys</td>
<td>2008</td>
<td>Lisbon (PT)</td>
<td>PET — positron emission tomography used as a new medical imaging system for the diagnosis of breast cancer</td>
<td>UPI-Instituto Superior Técnico (IST)</td>
</tr>
<tr>
<td></td>
<td>Plux</td>
<td>2007</td>
<td>Covilha/Lisbon (PT)</td>
<td>bioPlux — wireless and miniaturized signal acquisition system (great applicability in the healthcare area, particularly in physical therapy); powerPlux — package composed of signal acquisition hardware and automated signal processing software to allows sports technicians to rapidly evaluate and diagnose the physical conditions of their athletes; bioPlux motion — autonomous device with an integrated xyzPlux triaxial accelerometer</td>
<td>UBI/IST-UTL</td>
</tr>
<tr>
<td>Microelectronics/</td>
<td>CustomLenda Solutions, S.A.(Super Ego)</td>
<td>2005</td>
<td>Porto (PT)</td>
<td>RDPaint, NETmix, RIMcrop, nanoXIM, CDaps</td>
<td>FEUP/University of Porto</td>
</tr>
<tr>
<td>materials/equipment/</td>
<td>Fluidinova</td>
<td>2005</td>
<td>Porto (PT)</td>
<td>Composite materials used in musical instruments</td>
<td>FEUP/University of Porto</td>
</tr>
<tr>
<td>robotics</td>
<td>ideam, Lda</td>
<td>2008</td>
<td>Porto (PT)</td>
<td></td>
<td>UPFec — FEUP/University of Porto</td>
</tr>
<tr>
<td></td>
<td>Technology, Lda</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ownersmark SA</td>
<td>2008</td>
<td>Porto (PT)</td>
<td>Structural Composite Poles in Thermoplastic Matrix t</td>
<td>Universities of Minho and Porto</td>
</tr>
<tr>
<td>Company</td>
<td>Year</td>
<td>Location (Country)</td>
<td>Description</td>
<td>Collaborators</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
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<td>-------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Ply Engenharia</td>
<td>2006</td>
<td>Oeiras (PT)</td>
<td>OpenCell technology &amp; Multimaterial truck cargo bodies</td>
<td>IST/Technical University of Lisbon; FELIP/University of Porto; University of Coimbra; University of Aveiro</td>
<td></td>
</tr>
<tr>
<td>SeITech</td>
<td>2008</td>
<td>Lisbon (PT)</td>
<td>Robotic solutions, autonomous intelligent systems as well as hardware and software for embedded systems</td>
<td>IST/Technical University of Lisbon</td>
<td></td>
</tr>
<tr>
<td>Techsider Ltd</td>
<td>2008</td>
<td>Lisbon (PT)</td>
<td>Multiple-layered assemblage of wood and other natural based materials</td>
<td>Institute of Agronomy (ISA), Technical University of Lisbon</td>
<td></td>
</tr>
<tr>
<td>Tomorrow Options</td>
<td>2007</td>
<td>Porto (PT)</td>
<td>WakiSi and ChangeYourPosition are electronic, portable and wireless medical. The former to monitor and assess lower limbs condition and the latter to avoid bedsores or decubitus ulcers.</td>
<td>INESC Porto/FELIP/University of Porto</td>
<td></td>
</tr>
<tr>
<td>UAW Vision</td>
<td>2005</td>
<td>Lisbon (PT)</td>
<td>Aeronautics, Mechatronics, Remote Sensing. Low-cost autonomous aerial platform for agriculture, forest and surveillance applications</td>
<td>ISA/IST/Technical University of Lisbon</td>
<td></td>
</tr>
<tr>
<td>We Adapt</td>
<td>2008</td>
<td>Braga (PT)</td>
<td>FashionMe — “Haute Couture” and casual wear for disabled people with their own brand; BodyMe — devices for physical reconstitution</td>
<td>University of Minho</td>
<td></td>
</tr>
<tr>
<td>Fibersensing</td>
<td>2004</td>
<td>Maia (PT)</td>
<td>Developer and manufacturer of optical fiber Bragg grating (FBR) based sensor systems for advanced monitoring applications</td>
<td>INESC Porto/FELIP/University of Porto</td>
<td></td>
</tr>
<tr>
<td>IdMind</td>
<td>2000</td>
<td>Lisbon (PT)</td>
<td>Robotic kits, based on microcontrollers, used in a variety of innovation projects, up to complex robots developed for varied ends, such as: search and rescue, robotic soccer, art, and publicity.</td>
<td>IST/Technical University of Lisbon</td>
<td></td>
</tr>
<tr>
<td>ISA</td>
<td>1990</td>
<td>Coimbra (PT)</td>
<td>iLogger — multi-purpose autonomous (GSM/GPRS based, battery powered) remote management system providing data logging, automatic reading and alarms</td>
<td>ISEC/FCTUC/LEI (UC)/University of Coimbra</td>
<td></td>
</tr>
<tr>
<td>Multiwave</td>
<td>2003</td>
<td>Maia (PT)</td>
<td>Pulsed fiber lasers; optical sources</td>
<td>INESC Porto/University of Porto</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 16 complements the analysis first published by Conceição et al. [8] for the US and compares the ratio of public vs. private R&D expenditure in the total expenditure (vertical axis) and for basic expenditure only (horizontal axis) from the post-war period to 2006. Four stages can be identified in Fig. 16. First, the growth of total public funding overall through 1965, when public expenditure was twice as private expenditure. Throughout this period, the ratio in basic expenditure remained relatively stable at around 2, increasing to 2.5 at the peak of total public/private expenditure. This is the launch period of the US S&T system. Then, from 1966 through 1987, the total public/private ratio decreased rapidly but, at the same time, the basic R&D public/private ratio also increased sharply. This is the “first specialization” period, as US public funding focused more on basic R&D, and applied research and development was increasingly left to the private sector. Third, through the 1990s, the trend was that both ratios decreased, although the basic science ratio is still very high, at around 3. Finally, and surprisingly, since 2000 there has been a “second specialization” period, as US public funding again focuses more on basic R&D, with the private sector also increasing its funding of basic research, although at relatively moderate levels.

Following the analysis of Conceição et al. [8] we note another important aspect revealed by the structural analysis mentioned above: much of the retreat in public funding in the United States is related to the pulling back of financial support to defense-related R&D. In fact, for the first time since 1980, non-defense related R&D public expenditure in the United States is equal to
defense-related expenditure. It is also important to note that the abrupt decrease in public expenditure in 1987 is related to the beginning of the decrease in defense-related expenditure. Non-defense public expenditure on R&D in the United States has been tending to increase for more than 20 years.

The growth in non-defense public R&D expenditure in the US has gone mostly to health and to basic science. In 1999 the US Congress committed itself to doubling the funding of the National Institutes of Health (NIH, which funds research in health-related areas) and of the National Science Foundation (NSF, which funds basic science). Preliminary budget requests of the Bush administration for 2003 comply with this commitment, putting the funding of the National Institutes of Health at close to US$ 30 billion. But the analysis by Conceição et al. [8] has also shown that the public allocation of R&D resources to universities has exhibited a persistent upward trend over the last half century. While federal labs and private industry have historically received most of the federal funds (private industry with two large peaks in the mid-1960s and the mid-1980s), if current trends continue universities will become the main receivers of public support for R&D in the US.

Enhancing the level of public expenditure in the EU to improve the S&T environment in Europe has several policy implications. First, the debate on increasing expenditure in R&D in Europe needs to improve understanding of the different nature of private and public incentives for S&T. For instance, making blanket recommendations to enhance property rights or to limit public resource allocation may be misguided. The US experience shows that a diversity of policies and increasing institutional specialization, in addition to clarification of the role of private and public incentives to support S&T, are needed when making R&D policy. Increasing and strengthening public funding for R&D also requires funding to be directed towards academic and basic research in a way that will foster the knowledge infrastructure, offering funding that will provide companies with the necessary resources to increase their own investment in S&T, and allowing funding to foster the entrepreneurial environment and facilitate new entries in the market.

In fact, analysis shows that the need to modernize funding mechanisms, and to ensure a better balance between institutional and competitive funding for universities, has become a key issue in meeting the global challenges of research and international competition. This certainly includes the need to preserve the institutional integrity of the university [19], as well as to create flexible financial mechanisms to attract and secure new talents in Europe. But it may also, as shown by Paul David and Sten Metcalfe, increased competition and collaborative patterns among funding agencies in Europe [20]. We need to strengthen the role of the European Research Council and to foster additional competitive funding schemes with a transnational configuration by promoting collaborative arrangements among national funding agencies in Europe.

In this regard, and following the emerging discussion in Europe about the future of S&T [21], it is clear that, by and large, the financing of higher education and of science and innovation has occurred in Europe along rather traditional lines. Governments, and in many cases Ministries of S&T, directly undertake R&D or subsidize (directly or indirectly, through tax measures) R&D performance and technological innovation. Governments rise — or forego — revenue to pay for this support. Yet, the history of
science is rich with varied means of financing science and technological innovation. More importantly, developments in the size, integration, and technologies available in global capital markets present the opportunity to think about new financing possibilities and processes of societal engagement in S&T policies. These involve moving from traditional, “one-way” (and most of the time fragmented) government policies, to integrated multi-stakeholder policies involving a wide range of public and private agents. Again, the internationalization of funding agencies and mechanisms in Europe should be discussed in this context and in a way to contribute for the diversification of funding sources.

4. Which institutions fostering competence building for knowledge? The way towards reforming tertiary education

A key area of institutional reforming in Portugal with a considerable impact on knowledge production and diffusion has been the tertiary education system, which is under pressure to meet demands imposed by a globalized knowledge-society without compromising quality deliverance. This is because, in Europe, although most institutions and their staff have recognized the need for change for many years, the way institutions are organized, either internally, or through traditional links with society, as well as their structure of incentives, have continuously delayed reforms. Consequently, it is only in recent years that reforms have emerged directly conducted by governments in many different countries and political regimes. The Portuguese system is no exception to these mounting pressures and change has been recently introduced through governmental actions [22].

In the same way that the US S&T system as a whole is taken as a worldwide reference, the US university system is also used as a role model for its rapid responsiveness to economic changes and contribution to wealth creation [23]. There has been a growing understanding, mainly by European counterparts [24], that universities are important engines of economic growth and development instead of mere institutions of higher education learning for many years [25], with the increasing evidence of their importance as developers of regional industrial and technological development [26]. This is a role that US universities, and especially research universities, assumed throughout the second half of the 20th century [27].

Here, too, as with the whole US system, there is the perception that private funding associated with a high level of industry–science relationships stimulates the dynamics of academia, with a much more direct and greater impact on socioeconomic development at both regional and national level. The possibility of obtaining funding from private sources and incentives (such as intellectual property rights, IPR) is also appealing for European universities as they strive with increasing demands for change and for closer engagement with society.

At a time of increasing financial difficulties derived due to public budget constraints, there is the expectation that these links between research activity and its application in society will be reflected in more direct and immediate financial flows [28]. However, this perception is leading to an institutional convergence between what universities do (and are supposed to do) and what firms and other agents do. In fact, more than a decade after Burton Clark launched the idea of “entrepreneurial universities” [29], there is still much to learn about their impact and analysis [28] has clearly considered this convergence a potential threat to the institutional integrity of the university and the future of scientific research due to the commoditization of knowledge [29].

Above all, we follow Charles Vest [30], former MIT President, in his most recent book where he says “...what is best about American higher education — we create opportunity. That is our mission. That is our business. That is first and foremost what society expects of us.”

The issue is not to “save the university”, but rather to understand who will play the fundamental and unique role that universities have played in the overall cumulative system of knowledge generation and diffusion. It appears that the US is not willing to allow this integrity to be jeopardized. By misunderstanding US policies towards university-based research, there is a grave danger that European university policy will destroy these basic functions, which would be detrimental to the global production of knowledge, but would also certainly harm the development prospects of Europe itself, particularly in comparison with the US.

It is in this context that this paper attempts to deepen the emerging discussion facing the reform of tertiary education institutions (TEIs), and systems in coming years. The key role for policy makers and governments worldwide is to select priority actions and make the correct decisions: where and how to start the reform process?

For the purposes of this paper, we will use sample examples of the current Portuguese reform of tertiary education in order to illustrate our main arguments. This is because nearly three years since the OECD’s Education Policy Committee met in Lisbon to review Portugal’s higher education policy in December 2006, a number of steps have been taken to follow up on the Committee’s recommendations and a thorough legal reform of the Portuguese tertiary education system has been completed [31]. This brings about significant changes in the internal system of governance of TEIs (including their management structure), as well as in their external societal relations (including internationalization, research partnerships and business links, as well as external evaluation and accountability), which have been implemented together with an exceptionally large increase in public investment in S&T.

The remainder of this section focuses on two interrelated issues, which are central to understanding the reform of tertiary education institutions, namely: i) improving participation rates and fostering diversified systems for improved knowledge transmission and learning; and ii) strengthening knowledge production and internalization for improved knowledge networks, together with strengthening institutional integrity and systems linkages.

4.1. How to increase participation rates and improve learning?

Let us start with the need to open up tertiary education worldwide by strengthening the bottom of the pyramid. In fact, our underlying assumption is that students matter and that the main reason for governments to increase funding for tertiary education is to increase participation rates and extend the recruitment base and the number of students in tertiary education [32]. At the same time, it is also clear that new opportunities are required to give students more flexible pathways across different types and
levels of educational qualification, including through recognition of prior learning and credit transfer, in order to reduce repetition of learning. As a result, increasingly diversified systems are required, as discussed later in this paper.

But it is also clear that the need to modernize funding mechanisms and ensure a better balance between institutional and competitive funding for tertiary education is leading the discussion in governments worldwide. More important than discussing the details of funding formulas for institutional funding mechanisms, it is to review the overall share of institutional and competitive funding sources, as well as to promote student support mechanisms. This certainly includes the need to preserve the institutions' integrity (as discussed below), as well as to create flexible financial mechanisms to attract and secure new talents in our institutions and to meet the global challenges of research and international competition.

Still, the key issue is how to increase and balance loans and grants for students, as well as to develop innovative loan systems and to combine them with flexible legislation to accommodate reasonable student incomes through part-time work, particularly at TEsIs. Nicholas Barr [33] insists that the goal is to provide free education to all students, by guaranteeing that graduates will share the costs. However, the correct amount to be shared between taxpayers and graduates, as well as other private sources, is still to be determined, which must be done on socio-political and non scientific grounds.

Although income-contingent loan systems are becoming a common reference worldwide, as acknowledged by the OECD, it should be noted that their applicability is particularly dependent on the characteristics of the existing fiscal system. This is why in the fall of 2007 an innovative system of student loans was introduced in Portugal with mutual guarantees underwritten by the State, complementing the system of public grants, thereby improving access to higher education for all students. About 6500 loans had been contracted by summer 2009 through the banking system, which represents an important new achievement for Portugal and Portuguese families, following current practices in modern societies at the OECD level.

According to Michael Gallagher [34], the Portuguese initiative satisfies the key policy criteria: it is a horizontally equitable scheme; it represents good value for students; it is financially sustainable at higher volumes of student take-up; it is low risk for government and financial institutions; it avoids the need for additional administrative infrastructure. The loan facility reduces disincentives to study by covering reasonable living costs while deferring repayment obligations till after graduation. Still regarding the new Portuguese loan system, Nick Barr [35] applauded the facts that the scheme is universal; supplements existing grants rather than replacing them, and hence extends students' options; has no blanket interest subsidy; and has a highly innovative element of mutuality, which is the key that makes it possible for the scheme to make use of private finance. The loans scheme also has incidental benefits, by virtue of the requirements for progression and incentives for improving grade point averages. In particular, it should encourage students to develop their studies and complete their degrees, and to undertake courses that are more likely to lead to positive employment outcomes.

Let us move on to learning and teaching and the current debate in Europe. The global environment, the challenges facing higher education in Europe, and low levels of public expenditure on R&D underscore the need to engage in further higher education reforms within Europe, to address the S&T challenges, particularly in the context of the ongoing Bologna process. So far, reform efforts do appear to be leading to some successes. Even though the Bologna process is voluntary, most institutions recognize the great challenges and opportunities facing higher education in Europe and have made efforts to incorporate Bologna issues into their specific institutional strategies and activities. Furthermore, most institutions view the Bologna process as an opportunity to address many of the problems that have long existed in Europe. There are, however, challenges that remain in this reform movement to adapt higher education in Europe to the global environment and to improve funding for R&D. Understanding the relationship between the Bologna reforms and the social and national contexts in which they take place and expanding the European higher education policy dialogue to include more issues, remain significant challenges in the current process.

But, overall, changing the patterns of teaching and learning, making students’ work more active, and fostering student-centered education schemes, are our ultimate goals. We need to allow students to determine their own learning paths and trajectories, particularly through education cycles, but also across institutions in different regions and countries.

The debate requires tertiary education institutions in general to better understand how people learn. It is clear that learning systems vary considerably across the full spectrum of disciplines, with arts and medicine using project-based approaches and, probably, engineering and the social sciences following a more intense academic drift. But if the ultimate goal is to increase participation rates and the recruitment base of tertiary education, we believe the debate will gain from current knowledge of basic and secondary education levels.

The US’s National Academies report on “How People Learn” [36] provides clear evidence that “designing effective learning environments includes considering the goals for learning and goals for students”. Given the many changes in student populations, tools of technology, and society's requirements, different curricula have emerged along with needs for new pedagogical approaches that are more student-centered and more culturally sensitive. The requirements for teachers to meet such a diversity of challenges also illustrates why assessment needs to be a tool to help teachers determine whether they have achieved their objectives. But supportive learning environments, particularly fostering a culture of belief in science, need to focus on the characteristics of classroom environments that affect learning. In this respect, the authors were referring to the social and organizational structures in which students and teachers operate, including the environments created by teachers, but also out-of-the-school learning environments.

The idea that science should be considered as an open system, with diversified ways of participation, mainly derives from the fact that scientific activity is increasingly part of people’s lives, so that the training of scientists should not be restricted to a specific group of people, but should be rather a broad part of today’s education. In this context, it has become clear that the renewal of education systems has been particularly influenced by constructivism [37]. Following Piaget’s view of knowledge construction by using “active methods which require that every new truth to be learned be rediscovered or at least reconstructed by the student”, Seymour Papert [39] added the idea that knowledge construction “happens especially felicitously in a context where the
learner is consciously engaged in constructing a public entity”. And this is because “without knowledge, practice is limited and without practice, knowledge will never be fully realized” [40]. This constructionist viewpoint facilitates the “new milieu of discovery, learning, and sharing” mentioned above, and experience suggest that it: i) exposes students to a multi-disciplinary design experience; prompts participants to think about systems architecture; raises issues of organizational processes in a technical context; and builds learning communities of students, faculty, and staff.

Following the practices, skills, attitudes and values described above, education at all levels should take into account that learning a new practice requires moving through discovery, invention, and production not once, but many times, in different contexts and different combinations [41].

To achieve these objectives, we must learn from new research and, certainly, we also need to foster evidence-based project and experimental work, as well as to focus our attention on the transferable skills students should acquire. But we also need to reduce dropout rates in tertiary education and to involve students in research activities from the early stages. In summary, we need to go beyond the structure of tertiary education and gradually concentrate our efforts on measuring and taking stock of the diversity and evolution of specific student-centered parameters.

This type of discussion has led much of the current reform in Portugal, which promotes a “binary system” of tertiary education, with polytechnic education concentrating on professionally-oriented and vocational training, while university education should further concentrate on post-graduate education.

Non-university tertiary institutions are seen in many countries as nearer to the labor market and the more flexible arm of higher education. But, how to identify labor market needs, and how to provide the necessary skills, qualifications and technical know-how? Are non-university institutions more region-specific and consequently in a better position to judge the needs of local industry and promote local and regional clusters of innovation?

To a large extent, these questions remain to be solved. We also need to increase the number of adult students in tertiary education by removing barriers to their entry and success with due attention to the socioeconomic environment. This certainly strengthens the need for diversified systems of tertiary education, with greater differences in learning and teaching systems in professionally-oriented and science-driven programs.

In Portugal, full regulation that aims to bring tertiary education in line with the Bologna process was implemented very successfully, including the opening of higher education to new publics and the development of post-secondary education through the polytechnic sub-system: i) the 2007–2008 academic year, about 87% of initial training courses were already organized in accordance with the principles of the Bologna process; ii) the opening of higher education to new publics through the new access regime for adults (i.e., those over 23 years of age) resulted in the number of individuals entering tertiary education by this means rising to roughly 11,750 in 2007/08 and 10,850 in the 2006–07 academic year, up from around just 900 adults who began in tertiary education in the 2005–06 academic year; and iii) in 2007, a total of 190 short, post-secondary degree programs were given in higher education institutions, involving more than 4000 students.

It is also clear that we need to foster institutions that pay attention not only to emerging scientific and technological developments, but also to societal changes and the constant changes in the labor market. But we also need to look beyond our own higher education institutions and monitor students’ employability over the various education cycles. This is why in Portugal last year a new observation system was launched to monitor student demand through the twice-yearly publication of information regarding graduate job seekers registered in employment centers. In addition, under the new Higher Education Act, tertiary education institutions are required to collect and publish annual information on their graduates’ employment and career experiences up to five years after their graduation.

4.2. How to foster academic research and (international) systems linkages, together with institutional autonomy and integrity?

Let us now turn to the issue of reinforcing the top of our tertiary education systems, by fostering the internationalization and specialization of research universities. It has become a commonplace that we need to foster academic R&D and the internationalization of universities, particularly by promoting student mobility and university networks able to foster competitive research and learning environments and to attract and train highly qualified human resources [30]. The key issue is the creation of conditions to strengthen institutions and of the necessary critical masses to compete at the highest international level. There are two main aspects of the discussion.

First, the debate has confirmed that the progress of scientific and technological knowledge is a cumulative process, depending in the long run on the widespread disclosure of new findings. For example, Paul David [42] has consistently shown that “open science is properly regarded as uniquely well suited to the goal of maximizing the rate of growth of the stock of reliable knowledge”. As a result, universities should behave as “open science” institutions and provide an alternative to the intellectual property approach to dealing with problems in the allocation of resources for the production and distribution of information. Consequently, the main challenge for public policies is to keep a proper balance between open science and commercially oriented R&D based on proprietary information. At what level should governments foster cooperative exploratory research, which is recognized as to vital for the sustainability of knowledge-driven economies, in response to the increasing demand from individuals, research units and private firms for incentives for non-cooperative, rivalry knowledge?

Second, at the institutional level, graduate schools have been developed progressively worldwide over the past decade in diversified ways, ranging from interdisciplinary structures based in a single university (thus closely resembling the US model), to subject-specific inter-university structures. In general they aim to provide a better link between research training and research strengths and, in a few cases, have provided flexible structures to attract and contract researchers and graduate students in a way beyond that provided in traditional university departments. But, should we rely on structures beyond traditional departments in
order to promote research universities? And how can we ensure that graduate schools make their graduates more employable? Can the skills be transferable? And how is quality assurance to be ensured?

Again, this conceptual discussion drove much of the recent reform of Portuguese tertiary education, which was promoted in close interaction with the Government’s “Commitment to Science” [43], fostering public and private investment in S&T, including the extensive program of international partnerships with leading institutions worldwide presented above. Unprecedented in Portugal, these programs have facilitated the creation of effective thematic S&T networks involving a large number of Portuguese institutions in collaboration with companies and internationally renowned institutions. Unprecedented in Portugal, these programs facilitated the creation in 2007 of effective thematic networks of S&T involving a large set of Portuguese institutions in collaboration with companies and internationally renowned institutions.

The overall goal is to facilitate a long-term strategy to strengthen the country’s knowledge base, to foster economic growth and to enhance the quality of life in Portugal, by promoting the strategic coordination of public and private investments to explore international cooperation and industry–science relationships with leading institutions worldwide, in a way to sustain strategic investments in people, knowledge and ideas. In addition, analysis shows that scientific output in Portugal has increased by 18% over the last two years measured in terms of the number of internationally referenced scientific publications.

In this respect, and following some of the issues raised by John Ziman [5] many years ago and also noted by Nobel Laureate Richard Ernst [16], one critically important and emerging institutional issue relates to the training of students and young scientists in order to provide them with core competencies that help them to become successful researchers and prepare them with appropriate “transferable skills” for the job market outside research and academia.

Our final point concerns the need to preserve the institutional integrity of TEIs, at the same time promoting dynamic and responsive institutions, by widening the scope of diversity and of institutional autonomy, while ensuring effective accountability [19].

Many authors over the last two decades [44] have argued that whatever does not harm the institutional integrity of the university is acceptable. Companies and universities have evolved in a social context, to the point of attaining what these authors call “institutional specialty”. Thus, whereas companies are concerned to obtain private returns for the knowledge that they generate, universities have traditionally made it public. By means of this specialization, or division of labor, knowledge has accumulated rapidly, as is shown by the unprecedented levels of economic growth since the end of the Second World War.

This argument can be analyzed in detail, in the context of the knowledge-based economies [45]. The threats to a university's institutional integrity in fact go beyond the extension of its activities to links with society, which, if excessive, could lead to resources being spread too thinly. More serious problems may arise if higher education institutions take the path of privatizing the ideas that they produce and the skills that they develop.

We may begin by analyzing the higher education function of teaching, which contributes to the accumulation of knowledge, specifically of skills, through the formal process of learning through education, or “learning by learning”. This process is divergent [46]: a university education combines the transmission of codified knowledge by the teachers with the individual characteristics of the students, in a process in which the interpretation of ideas leads to the accumulation of unique skills. Given this situation, each student can benefit from these skills in the future.

Moving on to research, it is worth noting that the great majority of the ideas that are generated in universities are of a public nature, this being the essence of the specific contribution that the university makes to the accumulation of ideas. Incentives for the production of these public ideas come from a complex system of reward and prestige within the academic community. In a well-known survey of university teachers in the late 1990s in the US, the most satisfying factor, chosen by 86.2% of the sample, was autonomy and independence [47]. Again, the temptation to privatize university research results could threaten fundamental aspects of the way universities work and their essential contribution to the accumulation of ideas.

To summarize, our conclusion is that the institutional integrity of TEIs should be preserved, and an important point in terms of policy is that state funding of TEIs should not be reduced. However, this measure by itself is not enough. From a more pragmatic viewpoint, TEIs should respond to the needs of society, which include rapid and unforeseeable changes in the structure of the employment market and the need to furnish their graduates with new skills beyond purely technical ones, in particular learning skills. The need to promote dynamic and responsive TEIs involves widening the scope of diversity and of institutional autonomy, while ensuring effective accountability. Again, it must encompass preserving the institutional integrity of TEIs, while new forms of knowledge production (as put forwards since the early 1990s by Gibbons et al. [48]) should be considered in reforming TEIs and their links with society.

A diversified system presents advantages relating to research integrity. Analyzing the function of university research shows that it actually includes various sub-functions, not always clearly defined, but which should be the subject of distinct public policies and forms of management:

- **R&D, Research and Development**, which aims at the accumulation of ideas through convergent learning processes, which are associated with processes of knowledge codification. This is the commonest form of research, particularly in the context of economic development and from the standpoint of the relationship between universities and companies.
- **R&T, Research and Teaching**, in which research functions as a way of developing teaching materials, as well as of improving the teaching skills of the teaching staff, and which is also associated with convergent processes of knowledge codification.
- **R&L, Research and Learning**, in which the value of the research is not necessarily in the creation of ideas, but in the development of skills that enhance opportunities for learning. Research thus appears as a divergent function, associated with processes of interpretation.
According to the analysis of Conceição and Heitor [28] although the above sub-functions are strongly interconnected, R&D and R&T are more related to the creation of ideas. In this context, care is required in the choice of individuals with suitable skills for these types of activity. In turn, R&L is associated with a learning process, which seeks to develop learning skills through the experience of doing research.

In these circumstances a diversified system could respond effectively to the different demands made of it in the emerging economy, by being selective in R&D and R&T, and comprehensive in R&L. Indeed, in the context of the knowledge economy, the comprehensive nature of R&T should be extended beyond the university to cover the whole education system, as a way of promoting learning skills. In this situation, it seems essential to place renewed emphasis on education and, to a certain extent, to reinvent its social and economic role. Educational institutions must rethink their relationships with the individuals, families and communities among which they find themselves, presenting themselves as vital providers of opportunities to develop formal learning processes, while at the same time encouraging a way of life that promotes learning through social interaction.

To sum up, rather than presenting a detailed plan of public policy options and forms of management for higher education, in the above paragraphs we have addressed how the concepts developed in the literature can be used to analyze the challenges facing the integrity of university research in the knowledge-based economy, and what kind of opportunities can be discerned. Among our substantive conclusions are the importance of preserving the institutional integrity of tertiary education institutions, not only by avoiding excessive dissipation of their resources in activities related to their links with society, but most importantly by maintaining the academic character of their basic functions of teaching and research. In an environment in which education should promote learning skills, we highlight the need to identify and understand the different components of university research, so as to enhance the selectivity of the R&D and R&T sub-functions, while ensuring the widespread availability of R&L. It is argued that a diversified higher education system can free universities from many of the pressures that they are experiencing today, by helping to ensure the preservation of their institutional integrity.

The question that arises is how far universities can sustain their own independence and support integrity in research. To quote the Nobel Laureate Richard Ernst [16], “Universities should consider themselves as cultural centers with far-reaching radiance rather than merely serving as training grounds for academic specialists. The integration of knowledge, perception, and comprehension, as well as compassion, is at least as relevant as extreme specialization. Obviously, scientific excellence is indispensable, but insufficient in isolation.”

This leads us to better understand how effectively university networks can help to further basic university goals and preserve research integrity. In fact, many research universities have developed into new and innovative institutions, both national and international in scope, organized as consortia and combining in their open structures teaching, research, business incubators, culture and services. As universities develop new institutional capacities further challenges emerge. In particular, most universities are faced with the need to increase and diversify their sources of funding, as well as with increasing leadership and management functions.

Higher education institutions are under pressure to reform as a result of increasing global challenges. The relationship between universities and governments, their main source of funding and their governing authority in most cases, remains an uneasy one and often does not reflect the realities of an evolving political, social and economic environment. Multiple objectives should not be pursued at the cost of compromising learning and research environments for students, which also require continuous adaptation and improvements (such as in the new context of the Bologna process in Europe).

A final remark about the legal status of TEIs: we have seen, especially in continental Europe, that increasing the autonomy of TEIs has been one of the main objectives of sector reforms in different countries in recent years. Granting independent legal status to TEIs is one means of achieving this goal: it gives them greater autonomy to govern themselves and function as they see most appropriate, freely and independently, in pursuit of work that is deemed essential to society [49].

In addition, recognizing scientific knowledge as a public good implies the need to consider new dimensions in S&T policy that are designed and implemented in a way that fosters independent scientific institutions, among which the way in which transnational institutions are organized may provide a useful framework.

It is in this context, and again taking the case of Portugal, that the new Legal Framework of Higher Education Institutions approved by the Portuguese Parliament in September 2007 establishes the organizational principles of the higher education system, the autonomy and accountability of institutions, the establishment of governing Boards with external participation, diversity of organization and legal status of public institutions, particularly as private foundations, establishment of consortia, and recognition of research centers as part of the universities’ management framework.

5. Discussion and conclusions

We argue in this paper that the innovative capacity of a country depends largely on the concentration of knowledge integrated communities as drivers of larger communities of users. This, per se, requires a broad social basis and commitment for science policies and institutional reforms, in a way that effectively integrates multi-stakeholders and a wide range of public and private agents. This is discussed in the context of evolving and changing patterns in Portugal.

Portugal has recently achieved the average OECD level in terms of number of researchers per thousand workforce, and the need to double this figure in coming years and continue fostering advanced human resources is our main practical goal.

We now discuss three major implications of our analysis. First, we need to consider innovation together with competence building and to foster individual skills through the complex interactions between formal and informal qualifications. We need to...
widen the social basis for knowledge activities, including higher education enrolment, and we need to strengthen the top of the research system leading to knowledge production at the highest level. Numbers of graduates, on the one hand, and of PhD holders, on the other hand, remain well below European objectives.

Moreover, the European life-long learning landscape needs to be redesigned if Europe is to succeed. Higher education institutions are key to this reform, which should take into account the revolution arising from information technologies in the internationalization and inclusion of all sectors of society in the fabric of knowledge networks.

Second, we need to consider the social shaping of technology and the emergence of “human-centered systems”. This is because although incentives and infrastructure are essential to economic development, they do not tell the whole story of the differences across the various knowledge networks under development in Europe. Incentives and infrastructures do not operate in a vacuum, but shape and are shaped by the particular context in which they operate. In our analysis, the local context must have embedded a set of social capabilities that define the context in which knowledge networks evolve.

For example, analysis has shown that the mobilization of the information society must overcome some critical uncertainties [50], including: i) unclear expectations related to the level of dematerialization of social and economic activities; ii) effective adoption of new technologies by citizens and customers, which is particularly influenced by accessibility, affordability and usability; and iii) unpredictability of demand for interactive services from both localized and geographically dispersed communities.

Our evidence shows the critical need for appropriate management of these uncertainties and for suitable infrastructures, incentives and institutional frameworks to be promoted over time and across space.

Third, also we need to consider experimentation in social networks, which necessarily involves flows of people. It is organized cooperation between networks of knowledge workers together with different arrays of users that will help diffuse innovation. But establishing these innovation communities requires the systematic development of routines of collaboration on the basis of sophisticated research projects, not limited by administrative constraints and facilitating new forms of designing and using products and services. William Mitchell, from MIT, referred to these communities as “creative communities”, for which the experimentation of new ideas in “design studios” is particularly important to provide adequate forms of interaction of users with adequate research environments [51].

But we also know today that the development of these communities depends on attractive settings that facilitate the exchange of talents between the different poles of knowledge networks. It requires us to evolve from the old paradigms of “brain gain” to that of “brain circulation” among our regions. Let us remember someone that was born in Rotterdam, studied in Paris and in Louvain, did research in Cambridge and London, and worked in Basel. This is not new; happened some five hundred years ago with Erasmus of Roterdam, and our challenge is to make his story possible for all citizens.

To cope with such a variety of demands and with a continuously changing environment, tertiary education systems, in particular, need diversify. But the challenge of establishing modern tertiary education systems requires effective networks and a platform of research institutions, notably to stimulate political debate among the various stakeholders and to assist in the networking of national constituencies promoting the positioning of our institutions in the emerging pathways of brain circulation worldwide. We argue that strengthening external societal links and “system linkages” is critical in making the institutional changes required to meet the needs of global competition and the knowledge economy.

For example, the debate on the emerging reform of European universities analyzed in this paper in terms of the allocation and future evolution of R&D expenditure in Europe, must take into consideration the different nature of private and public incentives for S&T and foster the strategic collaborative involvement of both public and private stakeholders. Blanket recommendations to enhance property rights or to limit public resource allocation, based on perceptions of the US experience, may be misguided. In fact, the key message that emerges from analyzes of long-term patterns of US investment in S&T is that the development of the US S&T system was based on a diversity of policies that led over time to increased opportunities for citizens, as well as to increased institutional specialization based on a clear separation of the role of private and public incentives to support S&T.

To conclude, our analysis calls for policies that consider long-term approaches to dynamic environments, which need to be continuously monitored, assessed and externally evaluated. We need to focus attention on fostering advanced human resources and the concentration of knowledge integrated communities as drivers of larger communities of users. This requires a continuous public effort, but also a better understanding of the effectiveness of the mix of public support mechanisms and private incentives for the development of knowledge networks.

To clarify the debate, this paper brings together emerging issues worldwide and leads to new insights in science policy and technology commercialization. It discusses recent approaches to technical change in Portugal, based on an emerging diversity of policies and increasing institutional specialization and clarification of the role of private and public incentives to support S&T. This process is reflected in the trend in developed economies towards increasing private investment in S&T. We argue for the need to promote and integrate public and private strategies in modern societies fostering a non-hierarchical integration of formal policies and informal system linkages leading to knowledge-driven societies. This requires opening-up science policies to multiple public and private agents and includes the continuous adaptation of systems of competence building and advanced studies, among which reform of higher education is particularly highlighted in the paper.
References


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