ARTICLE IN PRESS
TFS-17791; No of Pages 17
Technological Forecasting & Social Change xxx (2013) xxx–xxx
Contents lists available at SciVerse ScienceDirect
Technological Forecasting & Social Change
journal homepage:

Developing human capital and research capacity: Science policies promoting brain gain

Manuel Heitor *,[1], Hugo Horta, Joana Mendonça [2]

Center for Innovation, Technology and Policy Research, Instituto Superior Técnico, Technical University of Lisbon, Lisbon, Portugal

ARTICLE INFO

Article history:
Received 29 October 2012
Received in revised form 18 June 2013
Accepted 9 July 2013
Available online xxxx

Keywords:
Science policy
Brain gain
Human capital
Advanced training
Research system
Higher education system and reform

ABSTRACT

Science policies emphasizing the advanced qualification of human resources, together with democratizing access to science and internationalizing the science base, are shown to help build the conditions needed to drive brain gain over time.

Exploring a new set of data for the period 1970–2010 in Portugal, this paper focuses on the analysis of flows of doctorates, with the ultimate goal of helping to promote the absorptive capacity that emerging regions and countries worldwide need to acquire to *learn* how to use science for economic and social development. It shows a notable process of brain gain by the end of this period and, above all, it provides a dynamic approach to the cumulative process of building knowledge-based societies. The results show the need to consider the co-evolution of brain gain, brain drain and brain circulation over time and space. In addition, they suggest the importance of certain major counter-intuitive policy instruments to facilitate the co-evolution of human capital formation and research capacity building. In the case of Portugal, these instruments have included a centralized program of research grants, research careers independent of traditional academic career tracks, and a diversified system of funding research units and institutions based on research assessments through international peer reviews.

1. Introduction

The main argument of this paper is the need to focus science policies in developing regions on the process of building advanced human capital, which requires stable public strategies over time, together with adaptable and resilient research institutions.

Critical mass is vital for the creation and dissemination of knowledge, and attaining that critical mass is of utmost importance for both developed and developing countries, and is particularly relevant for emerging regions worldwide [1–3]. The key role for policy-makers and governments in regions where major investments in science and higher education are being made is to select priority actions and make appropriate decisions as to where and how to start the process.

Our evidence and lessons learned show that achieving this ultimate goal requires science policies and strategies aimed at advanced human capital in a context in which alliances and partnerships between research organizations and higher education institutions, as well as between them and corporations, are of particular importance. Nevertheless, the main public policy issue relates to the conditions for fostering brain gain. This has become a politically sensitive issue worldwide and a critical one in developing and emerging regions [4].

It is against this background that our ultimate goal is to help understand the dynamics of brain gain, brain drain and brain circulation over time and space in order to deepen our current knowledge of policies that can drive brain gain in emerging regions worldwide [5,6]. This is important because brain gain depends on a cumulative process that is associated

* Corresponding author.
E-mail addresses: mheitor@ist.ut.pt (M. Heitor), hugo.horta@ist.ut.pt (H. Horta), joana.mendonca@ist.utl.pt (J. Mendonça).

[1] On leave during 2011–12 at Harvard University, Science Technology and Public Policy Program, at the Kennedy School. Secretary of State for Science, Technology and Higher Education in the Portuguese Government, 2005–2011.

[2] Previously at the Observatory for Science and Technology; Statistical Office, Ministry of Science and Education, Portugal.

0040-1625/$ – see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.techfore.2013.07.008

Please cite this article as: M. Heitor, et al., Developing human capital and research capacity: Science policies promoting brain gain, Technol. Forecast. Soc. Change (2013), http://dx.doi.org/10.1016/j.techfore.2013.07.008

with efforts to build knowledge-based societies [7]. In this context, our research hypothesis underlines that aspects of time and space and processes associated with the co-evolution of human capital formation and institutional building help promote the absorptive capacity that regions and countries need to acquire in order to *learn* how to use science for economic and social development.

It is clear that public policies to attract and retain talented people have mostly been focused on favorable immigration strategies [8]. We acknowledge the importance of such policies, but focus our argument on the need to promote science policies based on building advanced human capital and the internationalization of the science base.

Two further issues drove our research work and should be emphasized, as follows. First, innovation must be considered together with competence building and advanced training of individual skills through the complex interactions between formal and informal qualifications. This requires broadening the social basis for knowledge activities, including higher education enrolment, as well as strengthening the top of the research system to foster knowledge production at the highest level. It is well-known that the world's most developed regions (such as Japan and the US) have high rates of researchers per 1000 workforce, and are striving to increase these rates even further [9].

Second, strengthening experimentation in international knowledge networks necessarily involves flows of people. It is the organized cooperation among networks of knowledge workers, together with different arrays of users, that will help diffuse innovation in the design of products and services. But establishing these innovating communities requires the systematic development of routines of collaboration on the basis of formal education programs, sophisticated research projects, and a diversified and non-structured array of informal networking processes. This requires public policies, particularly science policies, to foster "brain circulation" between leading institutions worldwide.

As this point, we should remember that scientific progress is a source of development and that tertiary education institutions play a critical role in this process [10]. The investment of public resources in the context of rigorous international assessments leads to new knowledge, better advanced training of new human resources for society, and new ideas and processes, which increasingly result in innovation, modernization of institutions, improved quality of life, economic productivity and better employment opportunities [11].

Consequently, our goals require the renovation and expansion of the social basis for scientific and technological development. This calls for strong commitment 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 growing appropriation of scientific and technological culture by society was one of the central aspects of the analysis by Heitor [12] and here we explore that central principle, making use of a new set of data.

It should be noted that any analysis of this subject needs to be context-sensitive, taking into account changes in the mobility of talent and corresponding perceptions. The literature on the topic is itself in transformation, from the apparently one-way, inherently competitive and mutually exclusive mobility of the highly skilled (as understood as brain drain in both the internationalist and nationalistic views of Johnson [13] and Grubel and Scott [14]) to brain circulation [15]. In this framework, this paper is not intended to provide any type of recipe. Rather, it discusses lessons learned based on a historical analysis and under the assumption that science is contextualized [16]. As a result, we consider that knowledge diffusion processes are context-sensitive and should be oriented towards inclusive learning [17].

We base our analysis on a set of data on flows of doctorates in Portugal over the period 1970–2010. Portugal represents an interesting case study since continuous investment in science and technology in a small south-western European region has resulted in significant progress after some four decades of lagging behind [18]. In addition, a thorough legal reform of the Portuguese tertiary education system has been successfully completed [18,19] and there has been a uniquely large increase in public investment in science and technology [20].

The rest of this paper is divided into five parts. The following section describes the new set of data used for our analysis of Portugal in the period 1970–2010, together with the research methodology. Section 3 presents data up to 2010, the evidence on the achievement of brain gain after four decades of investing in the science base. Section 4 analyzes the evolution over time of relatively unstable science policies over those four decades, and Section 5 discusses structural factors that determine research capacity. In both sections, we use the number of doctorates as the main proxy for our analysis. The paper concludes with our main summarizing remarks and lessons learned in terms of the need for science policies in many different regions of the world to focus on advanced human capital formation and research capacity.

2. Methodology and data

The data used in this paper were made available by the services of the Ministry of Science, Technology and Higher Education responsible for gathering and publishing statistics [21]. They include identification of the professional situation of all doctorate holders whose studies were awarded at, or recognized by, Portuguese universities over the last four decades, as well as those working in Portugal in 2009. This identification was based on analysis of microdata from various sources of statistical and administrative information, on the basis of which all doctorate holders and their corresponding professional situation in 2009 were identified.

These doctorate holders can be divided into three groups, namely: 1) PhDs whose doctorates were awarded by Portuguese universities; 2) PhDs who gained their doctorate abroad and requested recognition, equivalence or registration of their degree in Portugal; 3) PhDs who gained their doctorate abroad and did not officially register their degree in Portugal.

The identities of the PhDs in each of these groups and data on their mobility and professional situation came from different information sources, gathered directly or administratively, as follows:

i) the official annual R&D survey of all entities that carry out research and development (governmental, higher education, private not-for-profit institutions and companies), including information on all their individual researchers;

Please cite this article as: M. Heitor, et al., Developing human capital and research capacity: Science policies promoting brain gain, Technol. Forecast. Soc. Change (2013), http://dx.doi.org/10.1016/j.techfore.2013.07.008

ii) the national register of ongoing doctoral theses, which is an annual survey of all higher education institutions that collects data on ongoing and completed doctoral theses, with information on the researcher, institution(s), field of science, supervisor(s) and abstract. This survey feeds annual information to the dataset of all PhDs whose degrees were gained at or recognized by Portuguese universities since 1970;

iii) the survey of careers of doctorate holders, which is a statistical operation that collects information on the categorization of PhDs, their academic training, professional situation, international mobility and scientific production;

iv) the biographical records of teachers in higher education, which collects annual information on the composition of the academic staff of all higher education establishments;

v) the employer–employee matched dataset collected annually by the Ministry of Labor and Social Security (*quadros de pessoal*), with information on firms, establishments and workforce, including information on individual employees' education levels. Data on employees with PhDs was confirmed directly with the companies hiring these individuals;

vi) administrative employment registers in the public administration sector, which include the list of entities hiring PhDs, who were contacted individually to provide detailed information about each individual;

vii) administrative data from the Portuguese Science and Technology Foundation (FCT), which include biographical data on post-doctoral fellowships funded directly by FCT, post-doctoral fellowships and contracts of PhD researchers funded by scientific research projects supported by FCT, and PhD researchers contracted by Associate Laboratories and research units supported by FCT (specifically in the period 2007–2009);

viii) administrative information on teaching staff at non-tertiary education institutions, gathered through the services of the Ministry of Education.

After the collection of data from these sources, a new dataset was built with a total of 19,876 doctorate holders identified by name and including their professional situation, work location, institution and job description. Individuals not found through these sources were searched through detailed internet surveys, which recovered information on a small number of individuals. Even so, the professional situation and workplace of 654 PhDs in 2009 could not be determined, which corresponds to 3.3% of the total number of PhDs identified.

3. Results: accumulated data

Table 1 reports the professional situation of all the doctorate holders identified, which indicates a brain gain for Portugal in 2009. Out of a total of 19,876 PhD holders, only 669 were found to be working abroad (3.4%), while 1836 foreign PhDs were working in Portugal. It should also be noted that 83% of these foreign PhDs are working in R&D-related activities [21]. In other words, the data on PhD holders in Portugal over the last 40 years show the increasing capacity of the country to attract talent and employ doctorates.

Table 1
Main flows of doctorates (PhDs) in Portugal over the last 40 years, 1970–2008.

1. PhDs awarded by Portuguese universities between 1970 and 2008	14,147
1.1 % PhDs working in R&D-related activities in Portugal (2009)	86.8%
1.2 % PhDs working in non-R&D-related activities in Portugal or in other circumstances (e.g. retired)	7.0%
1.3 % PhDs working abroad (2009)	3.7%
1.4 % PhDs with no identified workplace[a]	2.5%
2. PhDs awarded abroad and recognized by Portuguese universities between 1970 and 2008	4206
Portuguese nationals	3491
Non-Portuguese nationals	313
2.1 % PhDs working in R&D-related activities in Portugal (2009)	76.3%
2.2 % PhDs working in non-R&D-related activities or in other circumstances (e.g. retired) in Portugal (2009)	13.3%
2.3 % PhDs working abroad (2009)	3.5%
2.4 % PhDs with no identified workplace[a]	6.9%
3. Foreign PhDs with a PhD obtained abroad and not registered in Portugal or working in R&D in Portugal (2009)	1523
Flow of doctorates:	
Number of foreign PhDs or Portuguese nationals with a PhD obtained abroad working in Portugal (2009)	1836
3.1 % foreign PhDs working in R&D-related activities in Portugal (2009)	82.9%
3.2 % foreign PhDs working in non-R&D-related activities in Portugal (2009)	17.1%
4. Holders of PhDs awarded or recognized by Portuguese universities working abroad in 2009 (1.3 + 2.3)	669

[a] The maximum expected uncertainty of this analysis is associated with PhD holders with no identified workplace. Source: GPEARI (http://www.gpeari.mctes.pt/index.php).

In addition, the data show that the great majority of PhDs who gained their degree at Portuguese universities since 1970 were involved in R&D in Portugal (86%), mostly in higher education and research institutions, a total of 17,010 doctorates. Of these, 13,888 were working in the public and private higher education sectors, while 2427 were researchers in the private sector, and 695 were working in R&D in state laboratories and other public entities. In addition, only 4.5% of the total were not working in R&D, and 3.3% were retired [21].

The majority of PhDs whose degrees were gained abroad and recognized by Portuguese universities between 1970 and 2008 are working in Portugal (76.3%), also mainly at higher education and research institutions. Of these, 313 were foreigners. Additionally, 1523 foreign PhDs were identified as working in R&D in Portugal in 2009, although they did not apply for their degree to be recognized by a Portuguese university.

These results show that, in terms of flows of PhDs, a total of 1836 PhDs working in Portugal in 2009 were identified as either foreign nationals or Portuguese nationals whose doctorate was gained exclusively abroad. It should be borne in mind that this value is probably an underestimate, since there may be other PhDs who concluded their studies abroad and are working in Portugal, but who have not registered their doctorate and were therefore not identified.

There has thus been a positive flow of PhDs into Portugal (brain gain), mainly consisting of active researchers working in higher education or private research institutions. In order to better understand these results and to contextualize them in terms of developments in the Portuguese situation, it should be noted that Portugal has overcome a gap in scientific and technological development that had plagued the country for decades, indeed centuries, and has exceeded the OECD average in terms of researchers per thousand workforce [18].

That small statistic—going from 1.5 full-time researchers per thousand workforce in the late 1980s, to 3.5 in 2005, to 8.2 in 2010—tells an important story about how countries and regions can compete and level the playing field in the dynamic global economy. At the same time, the Portuguese tertiary education system has been reformed, the social basis for students recruitment has been enlarged and industry-science links have been strengthened, together with increases in business expenditure on R&D (which represented 0.8% of GDP in 2009, compared to 0.3% in 2005 and less than 0.2% until some ten years ago [20]). In this process of technological change, Portugal has seen the creation and nurturing of opportunities for research and advanced training through strategic partnerships with leading partners worldwide. These cover diverse areas, from deep-sea biotechnology in the North Atlantic to the internet of the future, and involve building further competencies in nano- and biosciences, as well as in engineering systems and advanced computing [22].

In general, an overview of the recent evolution of the Portuguese S&T system, and an explanation of the background of how Portugal achieved a brain gain of doctorates, can be gained from figures drawn from various reports produced by the statistics office of the “Ministry of Science and Technology”. We start with the scientific output of Portuguese research institutions in all scientific fields,[3] which reached 10,081 publications in 2009, from 6450 publications in 2005, and just 3792 in 2000. Also, that scientific output, as measured by the number of internationally refereed scientific publications in science and technology fields,[4] reached 7470 articles, letters, notes and reviews in 2009, up from 2702 in 2000.

Analysis also shows that: i) internationally refereed Portuguese articles, letters, notes and reviews in the exact sciences, natural sciences, health sciences, agriculture and engineering have increased nearly 2.8 times since 2000; ii) this growth can also be observed in the number of publications by total population, which reached 703 articles per million in 2009, from 373 in 2004; iii) the number of articles by total population is now 77% of the EU-27 average, whereas it was only 51% in 2004, suggesting that Portugal's science base in the fields of science, technology, engineering, and mathematics is becoming internationally competitive.

The above figures reveal the outcomes of public policies designed to foster investment in people and institutions. They reflect the growing number of researchers in Portugal, which reached 8.2 per thousand workforce in 2010 (about 46,000 full-time equivalent [FTE] researchers, nearly a quarter of them in the business sector). This figure is now above the EU and OECD averages, and is similar to (and in some cases even higher than) the levels of Austria, France, and the US.

However, the evolution is even more wide-ranging, as in recent years Portugal has had the highest percentage growth rate in Europe in terms of the total number of researchers (in FTE) per thousand workforce (about 95%), well above the European average (which grew by only 14% from 2003 to 2008), Spain (21%) and Ireland (13%). There has been an increase of 25% over the last two years in the number of researchers working in academic R&D centers (12,000 FTE doctorate researchers) and a doubling of the number of doctorate researchers since 2000.

The number of researchers (headcount) has also increased in all scientific areas since 2005. In 2008, 69% of all researchers in Portugal were performing research in the exact, natural, and agrarian sciences and engineering. However, despite accelerated growth in human resources for science and technology, and particularly of new PhDs, the growth rate in Portugal has remained relatively low compared with other European countries and US states. Even so, more doctorates are awarded per year in Portugal than in some comparable American states, such as Florida or New Jersey, having reached that position from a very weak starting point: in 1990, Portugal turned out a mere 0.68 new PhDs per ten thousand workforce [18].

4. Evolution over time—Learning from an evolutionary path

This section makes use of historical data for the last four decades, in order to shed light on the net accumulated results presented above. First, we look at annual data in terms of human capital formation, using the number of doctorates as the main proxy for our analysis. Second, we identify four major periods of science policy and science and technology development in Portugal, which are briefly described in a way that emphasizes key issues associated with human capital formation and institutional capacity.

4.1. Annual data: Portugal 1970–2010

Fig. 1 quantifies the number of doctorates awarded or recognized annually at Portuguese universities between 1970 and 2008. While this number was below 100 in 1970, it exceeded 1000 per year by 2003 and 1500 by 2008. Between 2000 and 2010, the number of doctorates grew by more than 74%.

Fig. 1 also shows the increasing capacity to train PhDs at a national level by an increasing number of universities. Until the late 1970s only the four oldest universities – the universities of Coimbra, Lisbon and Porto and the Technical University of Lisbon – had the capacity to award doctorates, even though the universities created in the early 1970s were also entitled to do so. Forty years later, 50% of all the doctorates awarded in Portugal are obtained at the oldest universities, which is typical of the evolution of other higher education systems worldwide [23,24]. This pattern alone shows the importance of time in the implementation of policies. Another important fact from this analysis is that the number of PhD degrees obtained abroad and registered in Portuguese universities continues to grow, even though its share vis-a-vis the total number of new PhDs is increasingly lower, another indicator of the system's evolving capacity to train PhDs.

Fig. 2 quantifies the ratio of PhDs obtained abroad to PhDs obtained in Portugal. While in the early 1980s the number of doctorates awarded abroad and recognized by Portuguese universities was similar to the number earned at Portuguese universities (about two hundred per year), in the last decade the capacity for awarding doctorates in Portugal has risen considerably, exceeding 1300 new doctorates in 2008. At the

[3] As measured by the Science Citation Index Expanded (SCI), together with other databases such as the Social Science Citation Index (SSCI) and the Arts & Humanities Citation Index (AHCI) using the fractional counting method.

[4] As measured by the SCI in relation to scientific publications in the exact, natural, and health sciences, as well as agriculture and engineering.

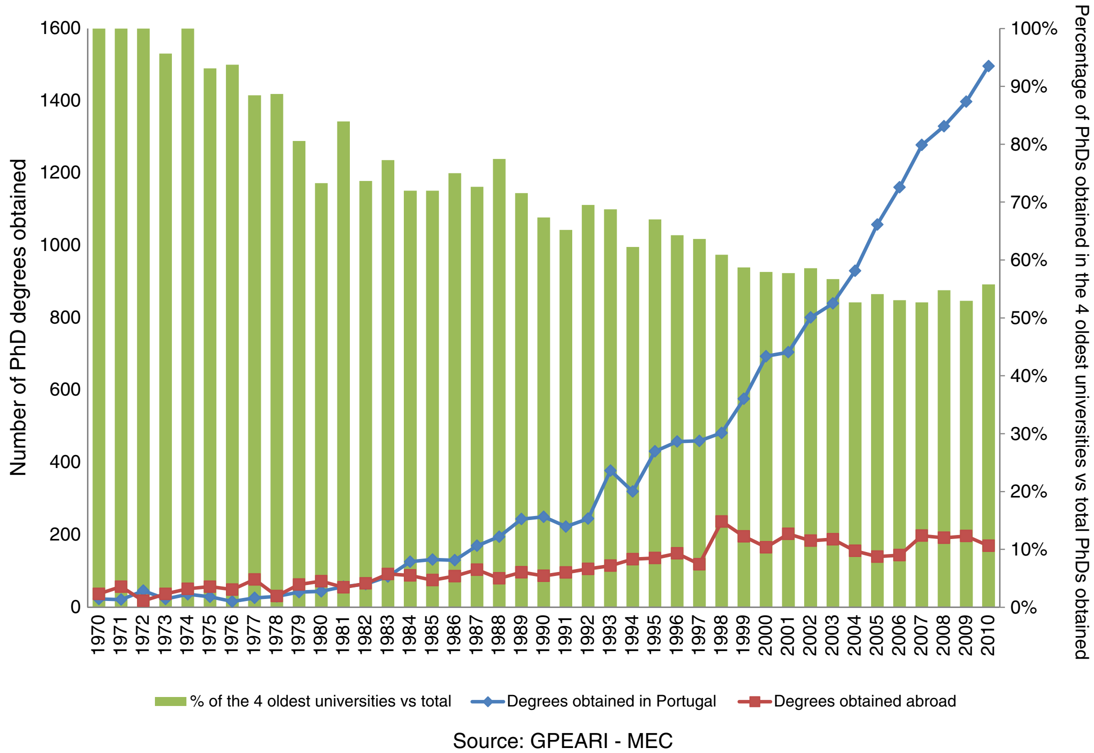


Fig. 1. Doctoral degrees concluded in Portugal and abroad, 1970–2010, and percentage of those obtained at the four oldest universities in Portugal (Porto, Coimbra, Lisbon and the Technical University of Lisbon).

same time, over the period under analysis, the number of new doctorates per year obtained abroad and recognized by Portuguese universities has remained nearly constant.

This reveals two major points with policy implications. First, until the mid-1980s the Portuguese higher education system did not have the capacity to train doctorates in general, and

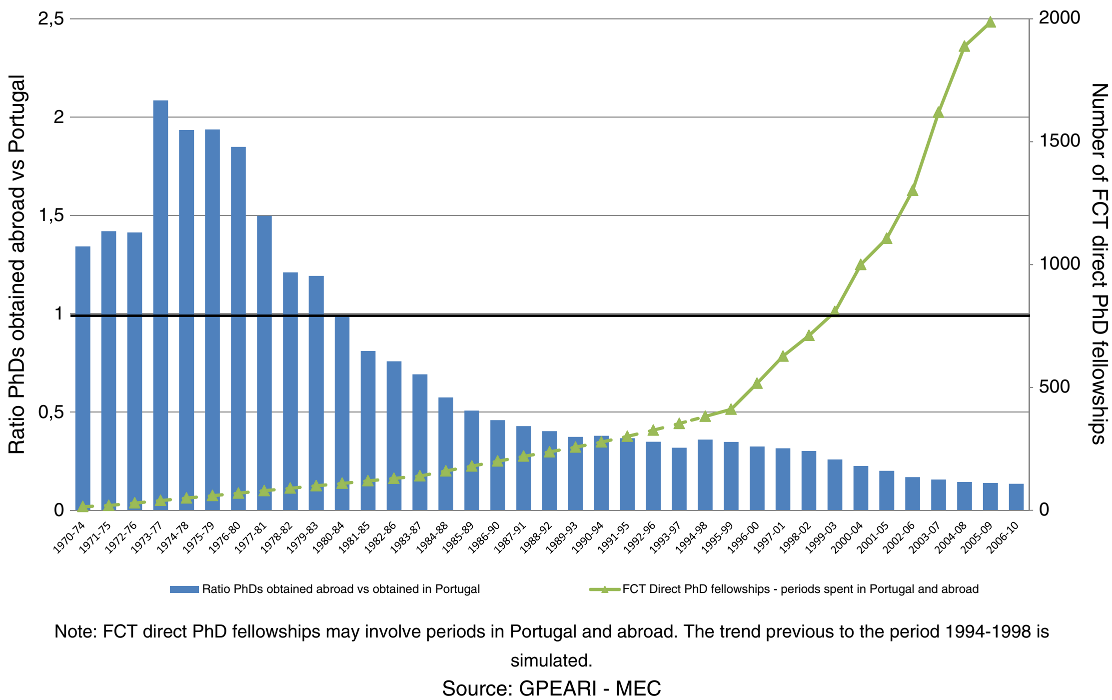


Fig. 2. Ratio of PhDs obtained abroad to PhDs obtained in Portugal, by five-year period, 1970–2010.

there was a clear lack of critical mass in many scientific areas. Second, mobility at doctoral level was treated as a strategic policy, to establish a science base in Portugal on the return of the doctorates, but also as a means to internationalize the Portuguese scientific and academic communities [25].

In the Portuguese case, in several universities disciplinary areas were created or fostered by Portuguese doctorates who had obtained their doctorates abroad [26]. Importantly, this mobility strategy was strongly supported by public policies that awarded a growing number of doctoral fellowships focused on the advanced training of human resources (see Fig. 2), but also on fostering internationalization and integration of Portuguese science into global research networks [27]. This was complemented in the initial years by grants and fellowships provided by private foundations, which have been active since the 1950s [28]. Again, this is a pattern that is echoed in other countries, such as South Korea, where highly skilled returnees are playing a major role in South Korean higher education by developing research areas, teaching programs and international networks [29].

Regarding the annual numbers of new PhDs in relation to the country's workforce, Portuguese universities awarded 2.7 new doctorates per ten thousand active workforce in 2008, whereas about twenty years ago, in 1990, Portugal produced only 0.68 new doctorates per ten thousand active workforce. In comparative terms, the state of Massachusetts (USA), Switzerland, Slovakia, Sweden and Finland produced more than twice as many doctorates per ten thousand active workforce in 2008. Particularly revealing is the number of new PhDs per ten thousand active workforce in the state of Massachusetts (7.6), and in Switzerland (6.8), which is practically three times the number in Portugal. Still, Portuguese universities granted more doctoral degrees in 2008 than some North American states, such as Florida and New Jersey, having reached this position starting from numbers that were very low until about ten years ago.

An obvious outcome of public investment in the advanced training of human resources in Portugal has been the growing qualification of academic staff at Portuguese higher education institutions. The percentage of academic staff holding a doctorate degree had reached 68% in public universities, 39% in private universities, and 19% in both public and private polytechnics by 2009, as opposed to 48% at public universities, 21% at private universities, and roughly 8% in both public and private polytechnics in 2001.

It should be noted that improvements in qualifications of academic staff have naturally been achieved in a context of "academic inbreeding" practices at the oldest universities, as measured broadly as the percentage of academic staff holding a doctorate from the same university. This practice is usually referred to in the literature as harmful to research productivity and collaboration [30]. It is still endemic in Portuguese academia, as acknowledged in the latest OECD tertiary education review of the Portuguese higher education system, which considered Portuguese universities as "too academic and inward looking, resulting in a high degree of insularity and inbreeding" [19: 146].

Fig. 3 presents evidence of the resilience of academic inbreeding with reference to the specific case of the Faculty of Engineering of the University of Porto, where academic inbreeding rates were high over a long period of time, remaining stable from the early 1990s up to 2010, ranging from 40% to 50% of the academic staff holding a doctorate, particularly at the assistant and associate professorship levels, suggesting a trend that will endure in future years.

This figure, however, is particularly relevant when considered together with Fig. 2, in the sense that academic inbreeding levels start to increase when most PhDs begin to be awarded in Portugal. The issue for policy is to what extent universities are able to change academic recruitment practices that are strongly rooted in institutional cultures and to what extent public policies can influence this change for the years to come.

In addition, it should be noted that the data in Fig. 3 do not include doctorate researchers independent of traditional academic careers. These doctorate holders have been critical for the development of Portuguese research capacity and the increasing scientific productivity of most research units and institutes, despite their temporary and insecure employment situation [31]. It is clear that they are liable to move from one institution to another and help to reduce levels of inbreeding in the oldest university schools [32]. This suggests a need for further policy instruments directed towards their integration into academic staff, as in a way to help renew the oldest institutions.

Returning to the qualification of academic staff, another phenomenon that needs to be taken into account is that average figures at a systemic level can hide different rates of evolution at the institutional level and in individual disciplinary fields. For example, Fig. 4 quantifies the qualifications of the academic staff of the faculties of medicine, engineering and law in three different universities and suggests that there are distinct institutional and disciplinary paths. On average, engineering faculties have been the fastest in adopting the PhD track for their staff, while in faculties of medicine the qualifications of their academic staff have either stagnated or actually worsened. This is an indication of the importance of specific disciplinary cultures, norms and habits [33], although the Portuguese case is also influenced by different levels of engagement in research [34].

4.2. Patterns in development of science policy and science and technology in Portugal

Following the chronological framework set out in Heitor and Horta [18], as inspired by Ruivo [35], the development of the Portuguese S&T system since the early 1970s, and its relationship with higher education and Portuguese society in general, can be divided into four main periods, as described in Table 2. In short, the S&T system was only effectively established after independent international research assessments started in the mid-1990s. In this respect, the first decade of the 21st century consolidated and strengthened earlier policies associated with vigorous public investment in R&D, together with a strong drive towards internationalization.

It should be noted that before the early 1970s we could only speak of a residual science base, with minor incentives for R&D in a non-integrated system, as designed by a totalitarian political regime, the *Estado Novo*. This regime was structurally averse to scientific knowledge, in which state laboratories were the main centers of scientific activity and universities were blocked from scientific development. As a result, the analysis in this paper starts in the early 1970s.

Please cite this article as: M. Heitor, et al., Developing human capital and research capacity: Science policies promoting brain gain, Technol. Forecast. Soc. Change (2013), http://dx.doi.org/10.1016/j.techfore.2013.07.008

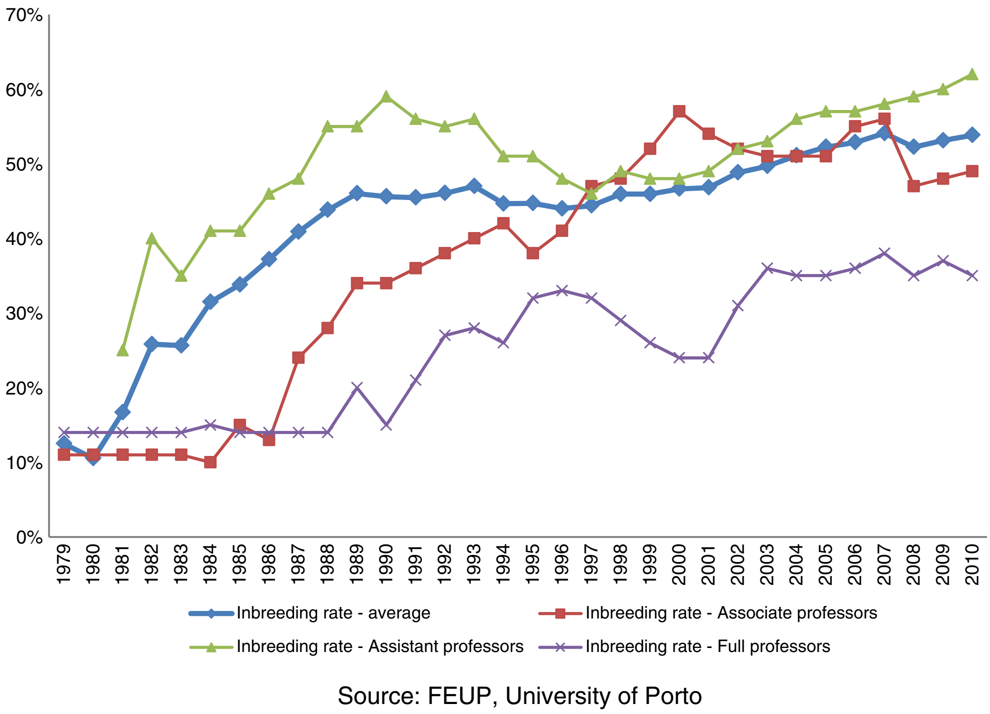


Fig. 3. Percentage of academic staff holding a PhD awarded at their own university ("inbreeding level")—the case of the Faculty of Engineering of Porto University, 1979–2010.

4.2.1. 1970–1985: Early attempts at growth, with 50% PhDs abroad and brain drain

The National Committee of Scientific and Technological Research (*Junta Nacional de Investigação Científica e Tecnológica*, JNICT) established in 1967, marked the beginning of science planning in Portugal. It was the outcome of several NATO studies during the early 1960s and was driven forward by the OECD project "Pilot Teams in Sciences and Technology" for Portugal, as commissioned by Minister Francisco Leite Pinto. This followed the Regional Mediterranean Project, which had focused on the conditions of education in Portugal and other southern European regions. But, at that time, overall expenditure on R&D was only about 0.25% of GDP, one of the lowest among European countries.

In the absence of incentives to promote the social and economic dimensions of the search for knowledge, a major education reform was launched in 1973 (the "Veiga Simão Reform"), which laid the foundation for the Portuguese science

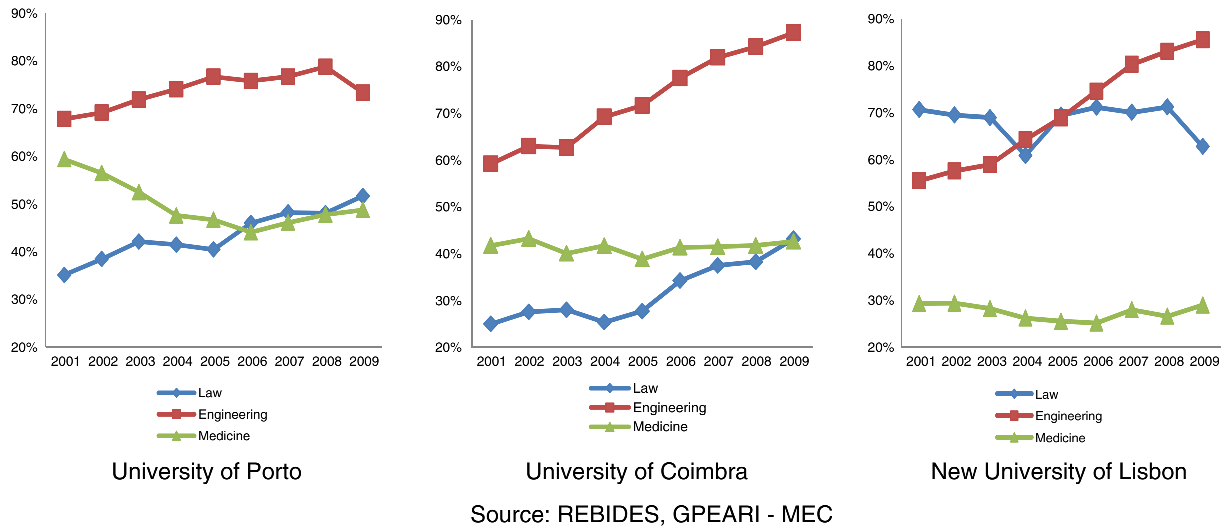


Fig. 4. Academic staff holding a PhD as a percentage of all academic staff, at faculties of engineering, medicine and law in three different Portuguese universities, 2001–2009.

Table 2
Main periods analyzed in this paper for the development of science policy in Portugal (1970–2010).

Period	Mobility trend	GERD/GDP	Total researchers (PhDs)	S&T policy instruments
1970–1985	Early attempts at growth, with 50% PhDs abroad; few PhDs in universities (brain drain); high academic inbreeding	0.28%	5736 (NA)	Creation of several universities in the mid-1970s (higher education policy); University and polytechnic career statutes
1986–1995	Striving to increase knowledge capacity; greater mobility to international scientific organizations (e.g. CERN); high academic inbreeding	0.49%	12,675 (NA)	Infrastructure building, competitive R&D projects and individual fellowship program (doctoral and post-doctoral)
1996–2005	Doctoral and post-doctoral fellowship program, increased brain circulation	0.76%	29,761 (12,152)	Performance-based funding of research units, through national research assessments, including the creation of large Associate Laboratories, to foster research excellence through networks of academic research centers; research career status; promotion of scientific culture and the public understanding of science
2006–2010	Increasing capacity; research contracts (moving towards brain gain)	1.7%	75,073 (23,125)	Scientific employment though competitive research contracts; University Chairs; reform of university governance and assessment systems; international partnerships promoting thematic networks of research and advanced training; further promotion of the public understanding of science

base. Grounded in an expanding higher education system, including the creation of new universities, this reform was shaped by a legal enactment recognizing the equivalence of doctoral degrees obtained abroad and restructuring the career path of academic staff. It should be noted that these legislative acts were passed more than ten years after Manuel Rocha's statement to the first congress of engineering education that "the fundamental aim of the university is to teach and disseminate culture, and this function cannot be performed without research activities" [36].

These ideals were only to become a reality in 1979 when the Statute on the careers of academic staff in universities took effect. This gave final and formal expression to the obligation on academic staff at university wholly and exclusively to undertake teaching and research. We hold this step to be decisive in establishing the science base in Portugal. It stipulated the necessary and basic conditions for R&D to be effectively performed in universities. As a pointer to the nascent dynamism thus unleashed, between 1967 and 1986 overall expenditure on R&D only rose from 0.25% to 0.36% of GDP. In 1982, across all subject areas, the country mustered 5736 research personnel and 9258 by 1986.

4.2.2. 1986–1995: The late awakening of the science base, still with brain drain and inbreeding

Joining the European Union represented an important opportunity for Portuguese S&T development. The period from 1986 to 1989 saw science policies guided by a more complex model of technological change and a strengthening of international cooperation, including membership of international organizations such as the *Conseil Européen pour la Recherche Nucléaire* (CERN). Under the leadership of José Mariano Gago, JNICT's President at the time, a "Mobilizing Program for Science and Technology" defined and implemented a series of S&T priorities and projects in specific areas. In the early 1990s, a number of new programs were implemented, supported by European Union structural funds, including a major initiative of individual research fellowships [25]. The CIÊNCIA Program, between 1990 and 1993, promoted advanced training and the construction of physical infrastructure. Under this program, 3204 fellowships – roughly half at PhD level – were granted and brought about a considerable increase in the numbers of Portuguese research staff. Several of these fellowships supported doctoral degrees abroad (54% of the total PhD fellowships awarded).

This period is characterized by academic inbreeding in the oldest universities, while university-science relations played a significant role in building the knowledge base at research and higher education institutions. Still, by 1995, compared to other European countries, Portugal presented a relatively low R&D effort, and its outlay on R&D remained below 1% of GDP, the second lowest figure among OECD countries. The institutional rigidity of universities led to the emergence of new interface institutions to draw on European Union funds, to encourage the flexible transfer of technology and, above all, to hire research staff.

4.2.3. 1996–2005: Struggling towards the European average, promoting brain circulation, still with inbreeding

In 1995, the incoming Government created the Ministry of Science and Technology, led by José Mariano Gago, a move that led to profound changes in public institutions associated with science and technology. The Portuguese S&T system was stimulated further by fundamental reforms in the assessment of R&D institutions. The new assessment system for R&D units, using international reviewers and linked to research funding, the publication of the methodologies employed and the results obtained, together with the right of appeal, guaranteed the independence and effectiveness of research evaluation. Investment in science increased significantly: for example, public funding for university-based research units rose from 7.5 million euros in 1995 to 25.5 million euros in 1999. In 1999, overall expenditure on R&D accounted for 0.76% of GDP, though this was still well below the European Union average of 1.74%.

The assessment exercise of 1999–2000 confirmed that successive assessments of S&T institutions since 1996 had injected a dynamic of change into the Portuguese research community, a change that had brought about a rapid increase in the numbers of young doctorates, doctoral students, and international connections, albeit still with strong patterns of inbreeding at leading institutions [37]. The steady increase in the number of doctorates, compared to European and international levels, was seen by the majority of assessment panels as decisive in gaining critical mass in scientific development. Even so, in 2000, the number of research staff plotted against the workforce still remained about half the European average — 2.9 per thousand workforce compared to 4.9.

4.2.4. 2006–2010: Fostering knowledge-integrated communities, moving towards brain gain

At the end of the first decade of the new millennium, science investment in Portugal took on a new lease of life, breaking with earlier pattern of relatively sluggish or fluctuating investments, and reaching unprecedented levels of development.

Above all, the build-up over two decades of public funding for the advanced training of human resources and the establishment of new scientific institutions began to bear fruit. Particularly clear was the impact on qualifications and on modernization of both higher education and business-based R&D, which increased considerably during these years. In 2006, the historical tipping point of 1% of GDP invested in R&D was finally reached. Three years later, in 2009, it was to attain 1.64%. Thus, Portugal overtook countries that historically had always invested more in R&D, among them Italy and Spain, with 1.26% and 1.39% respectively [38]. At the same time, the share of business in gross expenditure on R&D increased from about 20% to 50%, representing in absolute terms a threefold increase in business expenditure on R&D, which rose from about 400 million euros in 2005 to 1.3 billion euros in 2009.

The recent acceleration in the development of the Portuguese S&T system went hand in hand with its capacity to attract and train human resources and clearly bolstered the critical mass factor in academic institutions. It launched new provisions which brought researchers together across disciplines and built up knowledge-integrated communities with an increasingly marked international outreach. Thus, in Portugal research staff,

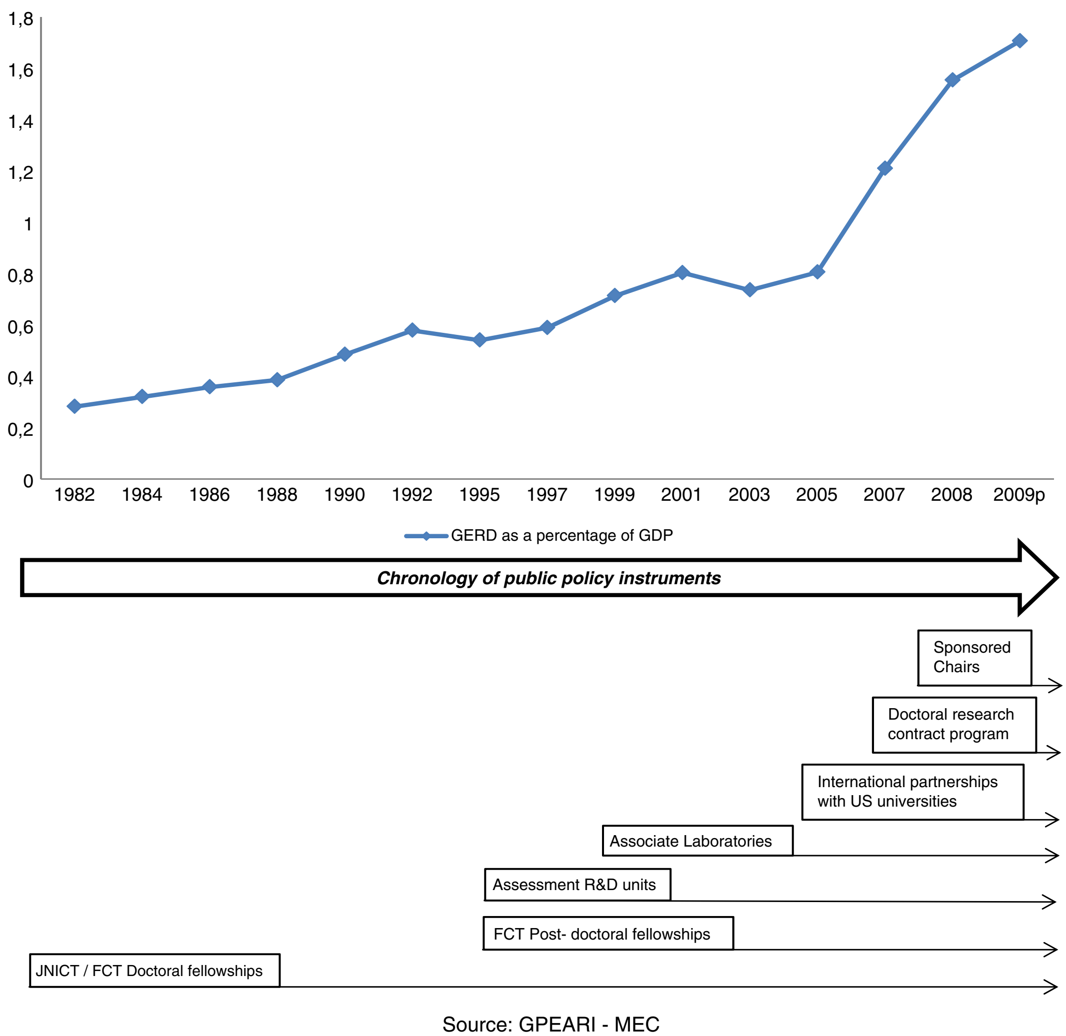


Fig. 5. Gross expenditure on R&D (GERD) as a percentage of GDP, and its co-evolution with major public policies and funding instruments aimed at promoting the Portuguese science base.

Please cite this article as: M. Heitor, et al., Developing human capital and research capacity: Science policies promoting brain gain, Technol. Forecast. Soc. Change (2013), http://dx.doi.org/10.1016/j.techfore.2013.07.008

expressed as the number of researchers per thousand workforce, reached the OECD average. In 2009, this stood at 7.9 per thousand, a level similar to – even higher than in some cases – Spain, Ireland, Italy, Germany, the Netherlands, and the United Kingdom [38].

5. Analysis and discussion: Structural factors determining research capacity

This section discusses the results presented above in terms of a novel contribution to the design of science policies in emerging regions worldwide. The data used are the basis for a dynamic approach to the cumulative process of attempting to build knowledge-based societies, and show the need to consider the co-evolution of brain gain, brain drain and brain circulation over time and space.

In the case of Portugal, it took almost four decades to achieve reasonable levels of investment in science and technology and to overcome the country's continuous lagging behind international standards. We argue that other regions worldwide can accelerate this process, if appropriate policy measures are systematically adopted to facilitate the co-evolution of human capital formation and institutional capacity building. In order to achieve these goals, the results presented above are discussed in the following paragraphs under four main headings, emphasizing major policy instruments that may be used in emerging regions worldwide to foster science and technology. We start by looking at levels of public investment, then move on to specific programs for human capital formation, including initiatives to promote scientific employment. Specific policies and instruments to foster research capacity through institutional building are also discussed. In addition, the need to promote science awareness in general is briefly addressed in terms of the challenges associated with the social construction of knowledge-based societies. We conclude our discussion with a brief identification of remaining challenges.

5.1. Levels of public investment in R&D and the maturity of a meritocratic culture

In the early 21st century, investment in science and technology in Portugal has reached – and gone beyond – the long-awaited moment when the amount set aside for R&D topped 1% of GDP. In 2009, gross expenditure on R&D attained 1.64%. Fig. 5 shows that there were three main periods of investment growth, of different intensities (1986–1992, 1995–2002, and 2004–2011), separated by periods of stagnation or reduction (1980–1986, 1992–1995, and 2002–2004), while Table 3 briefly characterizes the focus of policy instruments throughout each of these periods.

In the first period of growth, gross expenditure on research and development (GERD) as a percentage of GDP took ten years to double, from 1982 to 1992. At that time, the main science policy instrument was based on doctoral fellowships, a large percentage of which were still spent abroad.

In the second period of growth, from 1995 to 2002, GERD as a percentage of GDP grew by about 50% and new policy instruments were introduced, including post-doctoral fellowships, external independent assessment of research units with funding implications (based on three-year contracts), which was considered essential for the consolidation, integration and modernization of the Portuguese research system, and the creation and funding of large research laboratories with ten-year contracts (Associate Laboratories). From this time onwards, public policy maintained international research assessment exercises as a regular practice, assessing the output of scientific establishments and concentrating on achieving a critical mass of doctoral researchers across disciplines and institutions. Priority was consistently given to creating job opportunities in science to bring new blood into the science domain and to achieve critical mass. Much emphasis was placed on setting up international partnerships to foster scientific networks and industry-university partnerships, and on strengthening the bonds between graduate education and research.

After a period of stagnation, the third growth period, starting in 2005, saw the heaviest investment in science. By 2009, GERD as a percentage of GDP had doubled, mainly through existing policy instruments, although enlarged through additional public funding. The number of Associate Laboratories was increased, and new policy instruments were introduced. These included a major program to foster scientific employment through doctorate researchers on five-year contracts, the establishment of Research Chairs, and a program of international partnerships with prominent research universities and institutions worldwide.

As a result of the accumulation of public investment, the last few years have seen the emergence of three distinct but interrelated trends. First, there has been a remarkable increase in overall business expenditure on R&D (BERD) and in industry's capacity to undertake research in collaboration with academic research centers. BERD rose from 425 million euros in 2005 to over 1.3 billion euros in 2009.

Second, the relative spread across the number of firms investing in R&D has grown considerably. The five most R&D-intensive firms account for only 30% of BERD, the top twenty for 59%, and the top hundred for some 80%. These figures suggest that Portuguese business R&D is not dependent on a few large companies. This is a good sign for the overall goal of raising and sustaining the business sector's participation in the drive to increase the country's technological intensity. Nevertheless, analysis also suggests that large companies need to increase their R&D investment significantly if science-based job opportunities in the business sector are to increase. In addition, further specialization in the skills required by emerging areas is equally necessary if business competitiveness is to improve.

Third, there has been a considerable increase in academia's research capacity, with the number of PhD fellowships and post-doctoral research contracts more than doubling. Nevertheless, despite the impressive increase in investment in R&D in recent years, this still does not guarantee scientific maturity. Rather, given the development trajectory of Portugal's science system, it is more appropriate to regard investment as a further step in the recovery from a late awakening and its slow – and often intermittent – progress along the path to maturity.

The recent positive trend in science investment is best understood by comparing it with other European countries, not only over the same period, but over a longer time frame as well. From this longitudinal perspective, two main results emerge. First, despite reaching the same levels of investment as Spain, Italy or Ireland, Portugal's accumulated science investment over the past few decades is not even close to that of those countries. Building up the nation's scientific development to a

Table 3
Major science policy instruments used over time in Portugal (1970–2010), as identified in this paper.

Public policy instrument	Characterization/focus	Beginning	Ongoing
Doctoral fellowships	Centralized program oriented towards the advanced training of human resources, independently of university hierarchies	Late 1960s with JNICT; the number of fellowships and R&D projects increased substantially after 1986, through EU funds and particularly, after 1996, through FCT	Yes
Competitive funding program for R&D projects	Promoting research activities and research teams at national and EU levels		
Post-doctoral fellowships	Promoting the internationalization and mobility of doctorates; fostering knowledge production and participation in international knowledge networks	Mid 1990s after the creation of FCT in 1996	Yes
Promotion of scientific culture	Science education in schools and the public understanding of science	Since 1996	Yes
Performance-based funding of research units, through national research assessments (every 3 to 4 years), with 3-year contracts	Promoting research capacity though institutional building, independently of university hierarchies. Facilitating the creation of independent research units and the concentration of doctorates in research units	Mid 1990s with the creation of FCT; first assessment only with Portuguese reviewers; all the others are international assessments	Yes
Associate Laboratories: performance-based funding of large research units and networks, based on national research assessments, with 10-year contracts	Association and networking of the better qualified R&D units in the assessment exercise; focus on critical mass and renewal of the researcher base	Since 1999	Yes
International partnerships with leading universities and research institutes	Thematic research and advanced training networks, facilitating the internationalization of academic staff; increased R&D collaboration between Portuguese universities; Increasing the qualification of academic staff; academic exchange programs and pedagogical and scientific improvements	Since 2006	Yes
Post-doctoral research contracts program	Attraction of researchers nationally and internationally with a doctorate and some years of research experience; renewal of university academia	Since 2007	Yes
Sponsored research chairs	Attraction of foreign and Portuguese senior academics to Portuguese universities, co-sponsored by firms	Since 2007	Yes

position similar to the above countries requires a far larger and sustained investment in science, at a rate faster than in those countries, and over a long period.

Second, despite the investments in S&T during the periods analyzed, Portugal is still far from the investment levels of other small and medium-sized European Union countries such as Belgium, Austria, Denmark or Finland. One indirect consequence of these two features is Portugal's persistent “infantile status” in industry-science relationships and its present “immaturity” in both industry and academia in planning long-term joint ventures. This is affected by the structure of enterprises, as well as by the lack of large companies in sectors traditionally involved in advancing these ties in other industrialized countries.

5.2. Advanced training of human resources and human capital formation

Creating and enhancing critical mass is vital for the creation and dissemination of knowledge, and attaining that critical mass is of the utmost importance for both developed and developing countries, but is particularly essential for emerging regions worldwide. It is in this context that the main lesson to be drawn from the evolution of Portuguese research capacity towards a level characterized by a notable brain gain of advanced trained human resources is the importance of a major, long-term, publicly funded and centralized program of research fellowships. In addition, it should be noted that in recent decades it has been consistently based on independent national assessments of individual proposals, totally independently of any higher education institution.

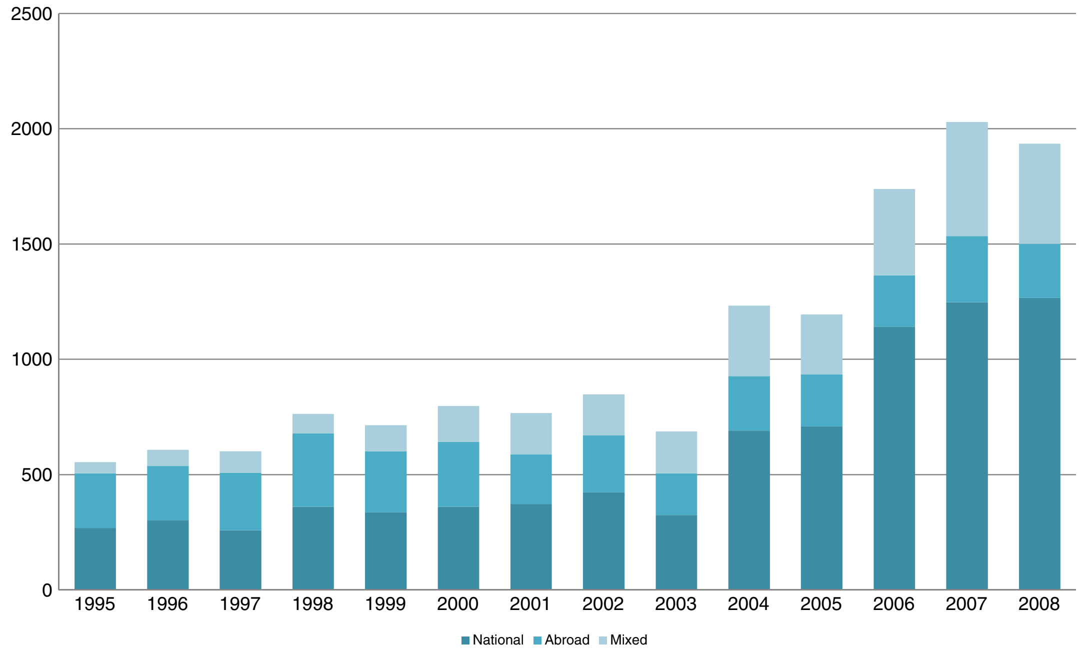
Four main points are discussed below, namely: i) the required accumulation over time of individual fellowships at doctoral and post-doctoral levels; ii) the nature of increasingly open competitions for individual fellowships, including the need to attract foreigners; iii) the need to evolve from fellowships to research contracts, at least at post-doctoral level and on a temporary basis; and iv) the role of academic inbreeding in the oldest universities.

Figs. 6 and 7 quantify the considerable public effort put into the advanced training of human resources and providing research-oriented careers, on a temporary basis, giving recent doctorates the opportunity to carry out research in a relatively independent fashion.

Nearly 14,500 doctoral fellowships and more than 4500 post-doctoral fellowships were awarded through a centralized program of individual grants from 1995 to 2008. All of them included an option for a spell abroad doing research or studying, for varying periods ranging from three months to the full study period abroad. This favored the mobility of researchers and the growing internationalization of the Portuguese research staff and academia [25,39]. Analysis clearly shows a gradual change in mobility patterns over time, with fewer fellowships spent fully abroad [32].

It should also be noted that, for the last fifteen years analyzed, foreigners were awarded more than 1100 doctoral fellowships (8% of all doctoral fellowships awarded) and more than 1500 post-doctoral fellowships (33% of all post-doctoral

Please cite this article as: M. Heitor, et al., Developing human capital and research capacity: Science policies promoting brain gain, Technol. Forecast. Soc. Change (2013), http://dx.doi.org/10.1016/j.techfore.2013.07.008

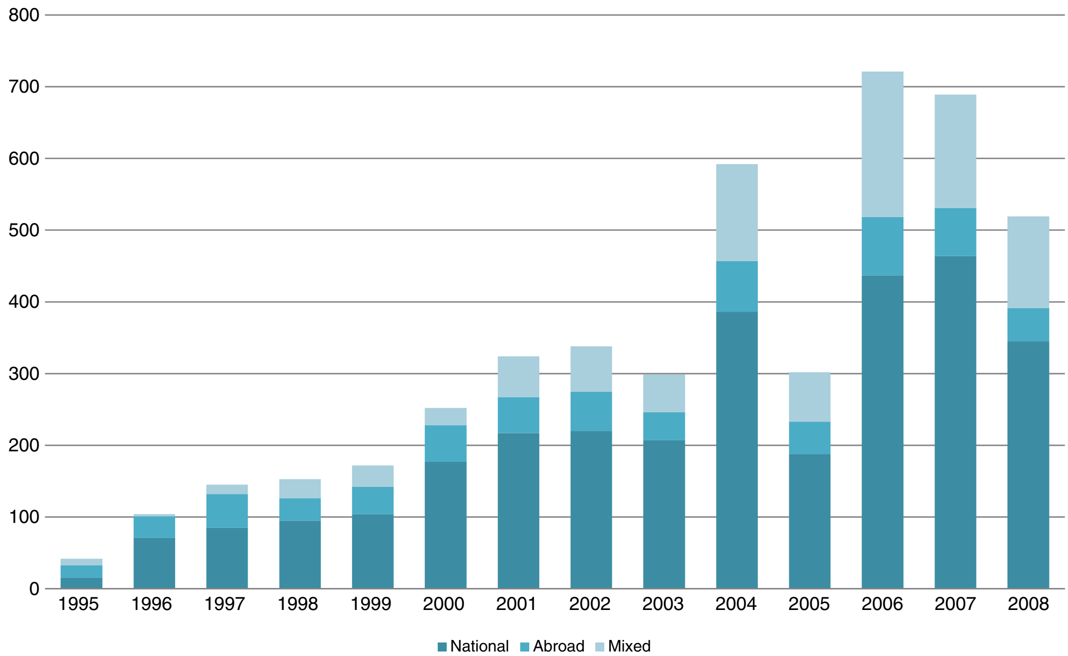


Source: Portuguese Science and Technology Foundation (FCT)

Fig. 6. National program for doctoral fellowships granted on a yearly basis, by mobility options, 1995–2008, funded through the Portuguese Science and Technology Foundation (FCT).

fellowships awarded) to do their doctorates at Portuguese universities or to engage in post-doctoral research. This has been a strategic asset in the international competition for talent and follows many other national strategies at a global level (see, for example, the Science Fellowship program in Japan, as discussed by [5]).

Our analysis also shows the importance of public policies that foster and create scientific employment through a



Source: Portuguese Science and Technology Foundation (FCT)

Fig. 7. National program for post-doctoral fellowships granted on a yearly basis, by mobility options, 1995–2008, funded through the Portuguese Science and Technology Foundation (FCT).

research career path in universities. This has gone beyond traditional academic careers, in a way that facilitated the continuous recruitment of young researchers to work in university research units, following best practices internationally, but independent of internal university procedures. As a case study, investment in people through qualified human resources was particularly promoted in Portugal in the period 2007–2010 to support contractual arrangements for researchers through academic university research centers and laboratories.

Fig. 8 presents the nationalities of the contracted doctorate researchers in higher education by early 2010, and shows the following main points. First, about 1200 new PhD researchers with more than three years of post-doctoral experience were hired by 2009, of whom 41% were foreigners. Unlike the internationalization of the student population at Portuguese universities (which relies on nationals from Portuguese-speaking countries [39]), the internationalization of the research community shows a predominance of nationals from the European Union and elsewhere in the world, with nationals from Portuguese-speaking countries accounting for only 4% of all the research contracts awarded. The hired PhD researchers were based at 264 research units in all areas of knowledge (around 43% in the natural and exact sciences and 24% in engineering and technology).

Second, this program stimulated major changes in the academic community and facilitated the renewal of teaching and research staff, although with less effect on faculty positions. The number of foreign academics in the Portuguese tertiary education system totaled 1400 in 2009 (an increase of 26% since 2001). Additionally, the number of foreign researchers almost doubled, from nearly 1900 in 2005 (6% of the total number of researchers) to about 3800 in 2008 (7% of the total).

5.3. Institutional building promoting research capacity

In addition to the human resources component, our research clearly shows that the co-evolution of human capital formation and research capacity building is critical to promote the absorptive capacity that emerging regions and countries worldwide need to acquire in order to *learn* how to use science for economic development. In this context, a key policy instrument in the Portuguese case was a public program to fund research units by multi-annual contracts based on national research assessments, totally independent of internal university hierarchies. This is again a long-term process, requiring different institutional speeds and types of multi-annual contracts.

Table 4 quantifies the impact of the national research assessments in Portugal, showing a substantial growth in the number of R&D units, but particularly a doubling of the average number of PhDs in each unit. This helped achieve critical masses at the institutional level, with clear effects in terms of the number of articles in international peer-reviewed journals and increased science-related networking at national and international levels [40].

The growth in the number of PhDs in R&D units, many of them based at or associated with universities, occurred independently of traditional academic careers and of internal university procedures; it was based on recruitment following best international practices. Fig. 9 reveals this by showing that the employment of doctorates in higher education has also followed this trend, as universities appear unable to absorb the new doctorates into their traditional academic staff.

This can be seen more clearly since 2003, when the number of new doctorates per year exceeded the 1000 mark. Although in the short term this is sustainable – as long as

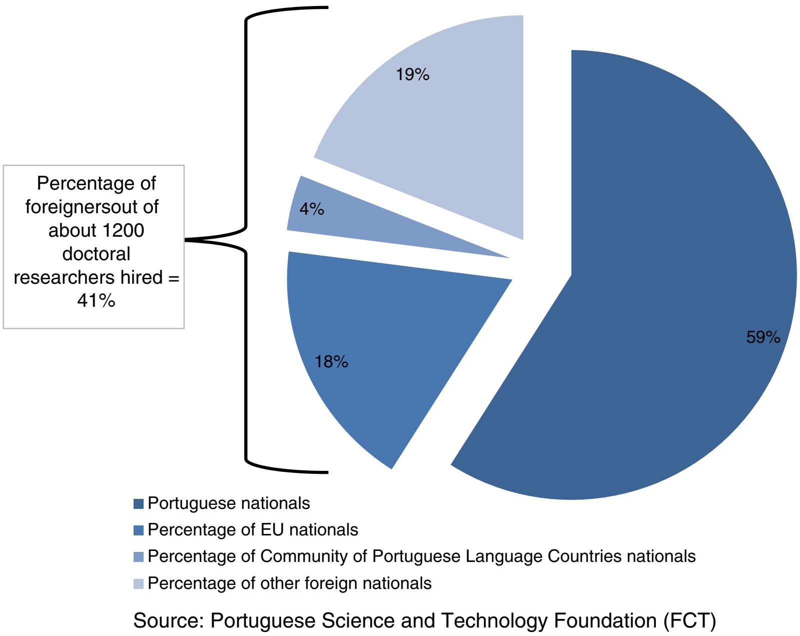


Fig. 8. National program for doctoral research contracts, publicly funded (2007–2009) through the Portuguese Science and Technology Foundation (FCT).

Table 4
Impact of national research assessments (every 3 to 4 years) in terms of number of research units, number of PhDs and average PhDs per research unit in Portugal.

Year of assessment exercise	1996	1999	2003	2007
Total number of research units	269	337	462	423
Total number of PhDs	3673	5850	8038	11,426
Average number of PhDs per research unit	13.7	17.4	17.4	27.0

Source: Portuguese Science and Technology Foundation.

there is funding available through post-doctoral fellowships and PhD research contract grants for a substantial share of the doctorates in the scientific system – in the medium and long terms it could lead to a situation of brain-drain [41]. As discussed above, this requires policy instruments designed to foster scientific employment throughout the labor market, with emphasis on industry [see also 42–45].

A landmark in terms of institutional building in the Portuguese research landscape was the establishment of Associate Laboratories in November 2000, through long-term contracts with the Portuguese Science Foundation (ten-year as opposed to the three-year contracts with typical research units). By 2001, 15 of these laboratories were active, bringing together 31 research units and more than 2200 researchers, of whom 880 were PhD holders. By 2009, the network of scientific institutions encompassed 510 research units and 25 laboratories. Overall, institutional funding amounted to some 80 million euros, compared with 5 million euros a decade earlier.

One of the main objectives of the Associate Laboratories was to increase scientific employment by recruiting both doctorate researchers and technicians. As a result, the average number of PhDs in Associate Laboratories is twice that of general R&D units. A second objective was to develop critical mass in every scientific discipline by bringing together comparatively large research consortia engaged in thematic networks across a number of institutions, selected by international assessment. In addition, Associate Laboratories opened the way for a new science culture, grounded in institutional autonomy, upheld by incentives and urged on by regular and on-going recourse to independent scientific assessment, a culture that has been developed and implemented in OECD countries and in most established and mature science systems [46].

At this stage, by 2005, the process of institutional building was oriented towards improving links between the research system and higher education institutions and private companies, while at the same time fostering institutional internationalization, as well as a greater internationalization of the science base at an individual level. This was achieved by establishing selected partnerships with leading research universities and institutes worldwide in the form of relatively large consortia bringing together universities, R&D units, end users and companies.

Table 5 summarizes the activities of a sample group of programs implemented through the Portuguese Science and Technology Foundation, unprecedented in Portugal and with innovative features worldwide, that have opened the way for a number of thematic networks with industry and with various Portuguese universities. In addition, these programs have been strategically important in their impact on doctoral education and advanced study programs, some of which were offered as dual degrees between leading US universities and Portuguese universities, and in bringing academics and researchers together in application-driven, collaborative research projects aimed at global markets [22].

Overall, the influence of incentive-based funding programs in promoting R&D is self-evident and has been decisive. Even so, different forms of incentives need complementary action to

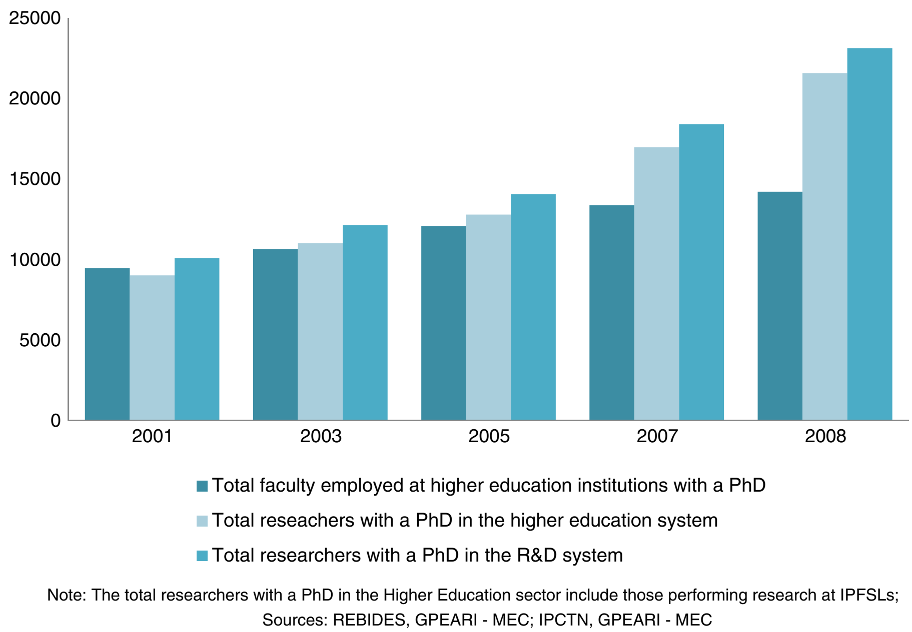


Fig. 9. Employment of doctorates in higher education over the last decade (2000s).

Please cite this article as: M. Heitor, et al., Developing human capital and research capacity: Science policies promoting brain gain, Technol. Forecast. Soc. Change (2013), http://dx.doi.org/10.1016/j.techfore.2013.07.008

Table 5
Sample of measures adopted through major international partnerships in science, technology and higher education in Portugal (2006–2011).

Program	Launched/signed	Human resources focus
MIT-Portugal	October 2006	Doctoral education: joint doctoral programs between Portuguese universities with research spells spent at MIT in bioengineering systems, engineering design and advanced manufacturing, sustainable energy systems, and transportation systems Master's programs and advanced studies programs in bioengineering systems, engineering design and advanced manufacturing, sustainable energy systems, and transportation systems; In collaboration with the Sloan School of Management, establishment of the Lisbon MBA with Portuguese business schools Creation of an educational consortium involving Portuguese engineering schools, other Portuguese schools (mainly of economics and social sciences), Associated Laboratories, state laboratories, industrial research laboratories and MIT
Carnegie Mellon-Portugal	October 2006	Doctoral education: dual doctoral programs between CMU and Portuguese universities in Computer science, electrical and computer engineering, software engineering, engineering and public policy, language technology, human–computer interaction, applied mathematics and technological change and entrepreneurship Faculty exchange programs bringing Portuguese academics to teach at CMU, and to learn new pedagogical and curricula perspectives Dual master's degrees between CMU and Portuguese universities in Entertainment technology, human–computer interaction, information technology/security, and software engineering Post-doctoral fellowships in mathematics (mainly applied mathematics, probabilities and stochastic methods)
Univ. Texas at Austin-Portugal	March 2007	Doctoral education: dual doctoral programs with the University of Texas at Austin and Portuguese universities, in Digital Media and Mathematics. Post-doctoral fellowships in Mathematics and Digital Media

increase the intensity and scale of R&D. Contract research is particularly important. If research is to take on a new dynamic, other incentives have to be brought to bear. Private sector firms, in particular, require other forms of encouragement, such as tax breaks for those actively engaging in research and innovation. In short, development of the science system rests on a variety of incentives.

5.4. Remaining challenges

The above discussion is centered on building research capacity through people and institutions. We conclude by briefly introducing further challenges in the development of research investment, the intensity of which is important in the sense that it quantifies the long-term stability of the research system, as well as helping to extend our understanding of the varied ways to promote the development of a science base.

Table 6 shows that in Portugal (and also Slovakia), the growth of the research system followed a path of relatively low (and, at times, decreasing) levels of funding per researcher, in order to give priority to the need to attract people and build critical mass. Our results show the success of such a strategy, even in an international landscape increasingly characterized by high level of competition for talent. Nevertheless, it is interesting to note that other countries in different national and international contexts, such as Spain and the Czech Republic, have followed slightly different patterns, achieving higher levels of funding per researcher, although with smaller relative concentrations of researchers. Importantly, for the case of Portugal and with relevance for developing countries and regions throughout the world, our results show that it is possible to grow a research system with relatively low intensities and still be sufficiently attractive to foster brain gain.

6. Conclusions

This paper provides a dynamic approach to the process of building knowledge-based societies in developing and emerging regions and countries worldwide through a new understanding of the co-evolution of human capital formation and research capacity.

Table 6
Evolution of the number of researchers (headcount) and funding per researcher (in 1000 US dollars PPP of 2008), in a sample of OECD countries for 2001 and 2008.

	S&T system			
	Total researchers (headcount)		Funding per researcher (1000 US$)	
	2001	2008	2001	2008
Czech Republic	29,216	44,240	65,064	71,256
Denmark	29,791	48,442	124,153	100,758
Estonia	4803	7226	21,203	39,758
Finland	47,534	55,195	94,804	113,089
France	217,173	289,478	158,104	127,223
Hungary	28,351	33,739	41,658	46,654
Iceland	3231	4158	76,981	71,339
Italy	100,442	145,623	160,582	131,594
Japan	792,699	890,669	128,280	138,265
Korea	178,937	300,050	116,172	127,555
Norway	34,864	44,145	74,268	82,071
Poland	89,596	97,474	28,456	34,782
Portugal	31,146	75,073	45,999	39,288
Slovakia	15,923	19,814	24,417	22,789
Slovenia	6740	10,124	79,689	79,827
Spain	140,407	217,716	57,973	67,975
Turkey	67,190	106,423	44,475	56,495

Source: OECD.

Please cite this article as: M. Heitor, et al., Developing human capital and research capacity: Science policies promoting brain gain, Technol. Forecast. Soc. Change (2013), http://dx.doi.org/10.1016/j.techfore.2013.07.008

The main data refer to Portugal over the period 1970–2010 and the paper explores primary source data focused on flows of doctorates in and out of the country. It shows a notable process of brain gain by the end of that period, which is discussed in terms of a new contribution to the design of science policies in emerging regions worldwide. The analysis shows the need to consider the co-evolution of brain gain, brain drain and brain circulation over time and space. It goes beyond commonplaces, leading us to argue in favor of a few major counter-intuitive measures and science policy instruments, as follows:

1. A central finding is that public investment in science associated with policies facilitating the co-evolution of human capital formation and institutional capacity building can lead to a situation of brain gain. In the specific case of Portugal, it took almost four decades to achieve reasonable international levels of investment in science and technology and to overcome a situation of continuous lagging behind international standards. This is shown to be associated with patterns of relatively sluggish or fluctuating investments in R&D for many years, reaching unprecedented levels of development only after 2008. We argue that other regions worldwide can accelerate this process, if appropriate policies are systematically adopted to facilitate the co-evolution identified in this paper. In our case, the number of researchers grew with relatively low levels of R&D funding per researcher, but at a level sufficiently attractive to foster brain gain;
2. In addition, our research suggests the key role of a major, long-term, publicly funded and centralized program of research grants, particularly for doctoral and post-doctoral grants based on independent national assessments of individual proposals, totally independent of any higher education institution. We argue that it is particularly important to implement this in the earlier and middle stages of development to prevent the investment being absorbed by the hierarchical and change-adverse environments that characterize many higher education institutions in developing regions;
3. Our analysis also shows the importance of public policies that foster a research career path in universities, independent of traditional academic careers, in order to facilitate the continuous recruitment of young researchers by academic research units following best international practices, but independent of internal university procedures. The relatively temporary and insecure nature of that research career path leads us to argue for the need for integrative measures to foster policies of gradual recruitment in the public and private labor markets;
4. Last, but not least, a public program to fund research units based on multi-annual contracts based on national research assessments, also totally independent of internal university hierarchies, helps build the institutional capacity needed in a knowledge-based society. This is again a long-term process, requiring different institutional speeds and types of multi-annual contracts.

Overall, our analysis shows that understanding aspects of time and space and processes associated with advanced training of human resources and institutional building helps to promote the absorptive capacity that regions and countries need to acquire in order to *learn* how to use science for economic and social development. In this developmental process, our data reveal that higher education institutions are the de facto main employers of PhDs and hence the advanced qualification of human resources needs to be considered in the context of full internationalization of their region/nation, in terms of facilitating the integration of those regions/nations in knowledge networks at the highest international level.

In attempting to extrapolate our results to developing and emerging regions worldwide, our analysis underlines the need to foster the advanced qualification of human resources and their international mobility during their training and early careers. In addition, we argue that science policies emphasizing the advanced qualification of human resources, together with democratizing access to science, help build the conditions that drive modern societies.

References

[1] J.N. Behrman, D.A. Rondinelli, The cultural imperatives of globalization: urban economic growth in the 21st century, Econ. Dev. Q. 6 (2002) 115–125.
[2] J. Chaloff, G. Lemaitre, Managing highly skilled labour migration: a comparative analysis of migration policies and challenges in OECD countries, OECD Social, Employment and Migration Working Papers, 79, 2009.
[3] S. Bertoli, H. Brucker, G. Facchini, A.-M. Mayda, G. Peri, The battle for brains: how to attract talent, in: T. Boeri, H. Bruecker, F. Docquier, H. Rapoport (Eds.), Brain Gain and Brain Drain, Oxford University Press, Oxford, 2011.
[4] P. Suntharasaj, D.F. Kocaoglu, Enhancing a Country's competitiveness through national talent management framework, Manag. Eng. Technol. (2008) 314–327.
[5] S. Mahroum, The international policies of brain gain: a review, Tech. Anal. Strateg. Manag. 17 (2) (2005) 219–230.
[6] A. Solimano, The International Mobility of Talent: Types, Causes and Development Impact, Oxford University Press, Oxford, 2008.
[7] D.K.-K. Chan, A comparison of Singapore and Hong Kong on their strategies for developing regional educational Hubs, Sociol. Stud. 2 (1) (2012) 1–25.
[8] A. Solimano, M. Pollack, International Mobility of the Highly Skilled: The Case Between Europe and Latin America, ECLAC, Santiago, 2004.
[9] OECD, OECD Science, Technology and Industry Outlook 2012, OECD, Paris, 2012.
[10] R.L. Geiger, C.M. Sá, Tapping the Riches of Science: Universities and the Promise of Economic Growth, Harvard University Press, Cambridge, 2008.
[11] P. Conceição, M.V. Heitor, H. Horta, R&D funding in US universities: from public to private support or public policies strengthening diversification? in: J. Enders, B. Jongbloed (Eds.), Public–Private Dynamics in Higher Education: Expectations, Developments and Outcomes, transcript-verlag, 2006.
[12] M.V. Heitor, A system approach to tertiary education institutions: towards knowledge networks and enhanced societal trust, Sci. Public Policy 35 (8) (2008) 607–617.
[13] H. Johnson, An “Internationalist” model, in: W. Adams (Ed.), The Brain Drain, Macmillan, New York, 1964.
[14] H.G. Grubel, A. Scott, The Brain Drain: Determinants, Measurement and Welfare Effects, Wilfrid Laurier University Press, Waterloo, 1977.
[15] A. Saxenian, Brain circulation: how high-skill immigration makes everyone better off, Brook. Rev. 20 (1) (2002) 28–31.
[16] H. Nowotny, P. Scott, M. Gibbons, Mode 2' revisited: the new production of knowledge, Minerva 41 (2003) 179–194.
[17] P. Conceição, M.V. Heitor, Knowledge interaction towards inclusive learning—promoting systems of innovation and competence building, Technol. Forecast. Soc. Chang. 69 (7) (2002) 641–651.
[18] M. Heitor, H. Horta, Science and technology in Portugal: from late awakening to the challenge of knowledge integrated communities, in: G. Neave, A. Amaral (Eds.), Higher Education in Portugal 1974–2009: A Nation, A Generation, Springer, Dordrecht, 2012.
[19] OECD, Reviews of National Policies for Education—Tertiary Education in Portugal, OECD, Paris, 2007.
[20] M.V. Heitor, M. Bravo, Portugal on the crosstalk of change, facing the shock of the new: people, knowledge and ideas fostering the social

Please cite this article as: M. Heitor, et al., Developing human capital and research capacity: Science policies promoting brain gain, Technol. Forecast. Soc. Change (2013), http://dx.doi.org/10.1016/j.techfore.2013.07.008

fabric to facilitate the concentration of knowledge integrated communities, Technol. Forecast. Soc. Chang. 77 (2010) 218–247.
[21] GPEARI, "Fluxo de Doutorados", Observatory for Science, Technology and Qualifications, Ministry of Science, Technology and Higher Education, 2011.
[22] M.V. Heitor, How far university global partnerships may facilitate a new era of international affairs and foster political and economic relations? Technol. Forecast. Soc. Change (2013), (submitted for publication) (A version of this paper was presented at the ASHE Annual meeting 2012, Las Vegas, November 2012).
[23] A. Yamanoi, Academic Marketplace in Japan, Tamagawa University Press, Tokyo, 2007.
[24] H. Horta, M. Sato, A. Yonezawa, Academic inbreeding: exploring its characteristics and rationale in Japanese universities using a qualitative perspective, Asia Pac. Educ. Rev. 12 (1) (2011) 35–44.
[25] H. Horta, The role of the state in the internationalization of universities in catching-up countries: an analysis of the Portuguese higher education system, High. Educ. Policy 23 (2010) 63–81.
[26] A. Delicado, 'Lá fora com um pé cá dentro': ligações dos cientistas expatriados ao sistema científico português, in: R. Carmo, J.A. Simões (Eds.), A produção das mobilidades: redes, espacialidades e trajectos num mundo em globalização, Imprensa de Ciências Sociais, Lisboa, 2009, pp. 177–202.
[27] M.T. Patrício, Science policy and the internationalization of research in Portugal, J. Stud. Int. Educ. 14 (2) (2010) 161–182.
[28] M.V. Heitor, H. Horta, Engenharia e desenvolvimento científico, in: J.M.B. Brito, M.V. Heitor, M.F. Rollo (Eds.), Engenharia em Portugal no Século XX, D. Quixote, Lisboa, 2004.
[29] S.U. Namgung, The role of returnees in internationalization at three Korean universities, in: B.D. Denman (Ed.), Proceedings of 35th Annual Conference of Australian and New Zealand Comparative International Education Society, International Co-operation through Education University of Auckland, 2007, pp. 172–189.
[30] H. Horta, F. Veloso, R. Grediaga, Navel gazing: academic inbreeding and scientific productivity, Manag. Sci. 56 (3) (2010) 414–429.
[31] E.R. Araújo, With a rope around their neck: grant researchers living in suspended time, New Technol. Work Employ. 24 (3) (2009) 230–242.
[32] H. Horta, B. Blasi, Why public policies fostering knowledge networks in academia matter? Insights from the Portuguese higher education system, in: J. Valimaa, D. Hoffman (Eds.), Change in Networks, Higher Education and Knowledge Societies—Empirical Analyses and Theoretical Perspectives, Springer, 2013, forthcoming.
[33] T. Becher, P. Trowler, Academic Tribes and Territories: Intellectual Enquiry and the Culture of Discipline, Second ed. Open University Press, Buckingham, 2001.
[34] H. Horta, On improving the university research base: the Technical University of Lisbon case in perspective, High. Educ. Policy 21 (2008) 123–146.
[35] B. Ruivo, As políticas de ciência e tecnologia e o sistema de investigação, INCM, Lisboa, 1995.
[36] M. Rocha, A Reforma do Ensino da engenharia – A Educação Permanente – A Investigação em Portugal, LNEC, Lisboa, 1962.
[37] M.V. Heitor, National evaluation of R&D units in Portugal, Portuguese Ministry of Science and Technology, 2001.
[38] MCTES, Science, technology and tertiary education in Portugal 2011, Paper presented at the OECD's Seminar on Science, Technology, Innovation and Higher Education Policy Developments in Portugal, Paris, 2011.
[39] H. Horta, Global and national prominent universities: internationalization, competitiveness and the role of the state, High. Educ. 58 (3) (2009) 387–405.
[40] H. Horta, T.A. Lacy, How does size matter for science? Exploring the effects of research unit size on academics' scientific productivity and information exchange behaviors, Sci. Public Policy 38 (6) (2011) 449–460.
[41] K. Thorn, M. Soo, Latin American universities and the third mission: trends, challenges, and policy options, World Bank Policy Research Working Paper No. 4002, 2006.
[42] D. Ernst, L. Kim, Global production networks, knowledge diffusion, and local capability formation, Res. Policy 31 (8–9) (2002) 1417–1429.
[43] E. Chacko, From brain drain to brain gain: reverse migration to Bangalore and Hyderabad, India's globalizing high tech cities, GeoJournal 68 (2–3) (2007) 131–140.
[44] S.-Y. Pan, Education abroad, human capital development, and national competitiveness: China's brain gain strategies, Front. Educ. China 6 (1) (2011) 106–138.
[45] R.L. Tung, Brain circulation, diaspora, and international competitiveness, Eur. Manag. J. 26 (2008) 298–304.
[46] G. Roberts, Review of research assessment: Report by Sir Gareth Roberts to the UK funding bodies, http://www.ra-review.ac.uk/reports/roberts.asp2003, (accessed 23 September, 2012).

Manuel Heitor is Full Professor at the *Instituto Superior Técnico*, IST, the engineering school of the Technical University of Lisbon, www.ist.utl.pt. From March 2005 to June 2011 he served as Secretary of State for Science, Technology and Higher Education in the Government of Portugal. Most recently, in the 2011–12 academic year he was a Visiting Scholar at Harvard University's Graduate School of Design and in the Science, Technology and Public Policy Program at the Kennedy School. He earned a PhD at Imperial College, London, in 1985 in combustion research and did post-doctoral training at the University of California San Diego. Then he pursued an academic career at IST, in Lisbon, where he served as Deputy-President for the period 1993–1998. Since 1995, he has been Research Fellow of the IC2 Institute, Innovation, Creativity and Capital, the University of Texas at Austin. His research work includes publications in the area of higher education policy, management of technology and the development of science, technology and innovation policies. He is co-editor of the book series on "Technology Policy and Innovation", launched through Greenwood Publishers, Connecticut and continued through Purdue University Press. He was the founding director of the IST's "Center for Innovation, Technology and Policy Research", which was awarded in 2005 by the International Association of Management of Technology, IAMOT, has one of the top 50 global centers of research on "Management of Technology". In 2003 he was awarded with the Dibner Award of the Society for the History of Technology, SHOT. He was co-founder in 2002 of "Globelics—the global network for the economics of learning, innovation, and competence building systems". He is a founding member of the Science and Technology Council of the "International Risk Governance Council", IRGC.While in the Government of Portugal, Manuel Heitor was successfully involved in attracting public and private investments on R&D, strengthening the research landscape of the country and in the reform and modernization of higher education. He was particularly instrumental in conceiving, implementing, and building up international consortia in research and advanced training with leading American universities, encompassing industry-science relationships and technology commercialization activities.

Hugo Horta is a researcher and deputy-director of the Center for Innovation, Technology and Policy Research IN+ at the Instituto Superior Técnico. After concluding his PhD, at the Technical University of Lisbon, in 2007, he started a post-doc focusing on the study of academic inbreeding in Portugal and Japan, through a joint project involving the Centro de Investigação e Estudos de Sociologia, ISCTE, Portugal and the Center for the Advancement of Higher Education (CAHE), Tohoku University, Japan. Throughout this period, he published articles focused on higher education diversity, scientific policies and funding, comparative scientific national structures, scientific productivity, internationalization of higher education, and academic mobility in international peer-reviewed journals, such as Management Science, Technological Forecasting and Social Change, Science and Public Policy, Higher Education, Higher Education Policy, Studies in Social Science and Asia Pacific Education Review.He is Coordinator editor of Higher Education, a leading journal in higher education research. He is on the editorial boards of the Mexican Journal of Research in Education and Asian Pacific Education Review. He also co-edited two books and a special issue on "Academic knowledge production, diffusion and commercialization: policies, practices and perspectives" published in 2011, at Science and Public Policy. In 2011, he also co-edited a special issue on "Network ethics in the growing global, multi-dimensional and technological academy" at the *International Journal of Cyber Ethics in Education* in collaboration with William Boyd from South Cross University, Australia. After a spell as Advisor of the Secretary of State of the Ministry of Science, Technology and Higher Education, from 2010 to 2011, he returned to academia to work as a Researcher at the Technical University of Lisbon, and has recently being developing research in Asia, with research visiting periods at the University of Hong Kong and at the University of Macau. He is also the Portuguese National delegate to the ERA Steering Committee on Human Resources and Mobility and the Chair of the ERA Working Group "Grant Portability", analyzing the possibility to establish a grant portability scheme among European countries.

Joana Mendonça holds a PhD in Engineering and Industrial Management at the Technical University of Lisbon, with a thesis entitled "The Impact of Knowledge Creation and Accessibility on Entrepreneurial Activities". She has completed her Master in Engineering Policy and Management of Technology, with a dissertation on the "Determinants of Innovation in the Portuguese Chemical Industry". She has a Diploma in Chemistry from Lisbon University. From March 2010 to December 2012 she has been deputy director for the Science, Technology and Higher Education Statistics Office, at the Ministry for Education and Science, the former Ministry for Science, Technology and Higher Education. In 2009–2010 she was an assistant to the Secretary of State for Science, Technology and Higher Education, in the Government of Portugal. She has been a researcher at IN+, the Center for Innovation, Technology and Policy Research at IST since 2002. Her research has focused on innovation processes, and new business creation, especially in human capital aspects on innovation and entrepreneurial activities.

Please cite this article as: M. Heitor, et al., Developing human capital and research capacity: Science policies promoting brain gain, Technol. Forecast. Soc. Change (2013), http://dx.doi.org/10.1016/j.techfore.2013.07.008