

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

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Highlights

Portugal over the period 1970-2010 shows a notable process of brain gain

The co-evolution of human capital formation and institutional capacity building lead to brain gain

Academic inbreeding at micro levels for some time periods help building “absorptive capacity”

Performance based research funding established upon national assessments builds capacity

Science policies emphasizing advanced qualification of people drive modern societies

Abstract

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

By providing a dynamic approach and exploring a new set of data from Portugal over the period 1970-2010, this paper focus on the analysis of flows of doctorates with the ultimate goal to help promoting the absorptive capacity that emerging regions and countries worldwide need to acquire to *learn* how to use science for economic development. It shows, by the end of that period, a notable process of brain gain and, above all, it provides a dynamic approach to the cumulative process of attempting to build knowledge-based societies. The results show the need to consider the co-evolution of brain gain, drain and circulation over time and space. In addition, they suggest the importance of a few major counter-intuitive policy instruments to facilitate the co-evolution of human capital formation and research capacity building. These instruments have included, in the case of Portugal, a centralized program of research grants, research careers independent of traditional faculty career tracks, and a diversified system of funding research units and institutions established upon 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 the utmost importance both for developed and developing countries, but a focus that is particularly relevant for emerging regions worldwide [1, 2, 3]. The key role for policy makers and governments in those regions where major investments in science and higher education are being made is to select priority actions and make the correct decisions: where and how to start the process?

Our evidence and lessons learned are that achieving this ultimate goal requires, *per se*, science policies and strategies towards advanced human capital in a context where alliances and partnerships among research organizations and higher education institutions, as well as between them and corporations, gain significant relevance. Nevertheless, the main public policy issue is related with the conditions fostering brain gain. This has become a rather politically relevant issue worldwide and very much critical in developing and emerging regions [4].

It is under this context that our ultimate goal is to help understanding the dynamics of brain gain, brain drain and brain circulation over time and space in a way to deepen our current knowledge about policies that may drive brain gain in emerging regions worldwide [5, 6]. This is important because it certainly depends on a cumulative process associated with attempting to build knowledge-based societies [7]. Under this context, our research hypothesis underlines that time, space and processes associated with the co-evolution of human capital formation and institutional building help promoting the absorptive capacity that regions and countries need to acquire in order to *learn* how to use science for economic development.

It is clear that public policies to help attracting and retaining talented people have been mostly focused on favourable immigration strategies [8]. We acknowledge the relevance 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 leading to knowledge production at the highest level. It is well known that the most developed regions of the world have high rates of researchers per 1000 labour force (see Japan and the US), and are striving to increase even more those rates [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 and the design of products and services. But establishing these innovation 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 processes of networking. This requires public policies, notably science policies, to foster “brain circulation” between leading institutions worldwide.

As this point, we must remember and recognize that scientific progress is a source of development and that tertiary education institutions play a critical role in this process [10]. Public resources invested under rigorous international assessments lead to new knowledge, better advanced training of new human resources for the society, new ideas and processes, which increasingly result in innovation, modernization of institutions, improved quality of living, economic productivity and better employment [11].

Consequently, our goals require the renovation and expansion of the social basis for scientific and technological development. This calls upon strong conviction not only from the scientific and technical professions and of public and private research organizations, but also from students and from the general population. The growing appropriation of scientific and technological culture by society has been one of the central aspects of the analysis of Heitor [12] and here we explore that founding principle, making use of a new set of data.

It should be noted that any analysis of this thematic needs to be context sensitive, taking into account the changes and perceptions concerning the mobility of talent. The literature on the topic is itself in transformation, from the apparently unidirectional, inherently competitive and mutually exclusive mobility of the highly skilled (as understood as brain drain in both its 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 a scope that “science is contextualized” [16]. As a result, we consider that knowledge diffusion processes are context-sensitive and should be pursued towards inclusive learning [17].

We depart our analysis from a set of data focused on fluxes of doctorates in Portugal over the period 1970-2010. Portugal represents an interesting case study since a continuous investment in science and technology in a small south-western European region resulted in significant progress after some four decades of lagging behind [18]. In addition, a throughput legal reform of the Portuguese tertiary education system was successfully completed [18, 19] and implemented together with a unique increase in the public investment in science and technology [20].

The remaining of the paper is organized in five parts. Next section describes the new set of data used for our analysis about Portugal in the period 1970-2010, together with the research methodology. Section 3 presents accumulated data by 2010, providing the evidence about attaining brain-gain after four decades of investing in the science base. Section 4 analyses the time evolution of relatively unstable science policies throughout those four decades and Section 5 discusses structural factors determining 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 world regions to emphasize advanced human capital formation and research capacity.

2. Methodology and data

The data used in this paper was made available by the services of the Ministry of Science, Technology and Higher Education (MCTES) responsible for gathering and publishing statistics [21]. It has included

the identification of the professional situation of all doctorate holders whose studies were earned at, or recognised by, Portuguese universities over the last four decades, as well as those working in Portugal in 2009. This identification was based on the exploration of microdata from various sources of statistical and administrative information that made possible the nominal identification of all the doctorates and their corresponding professional situation in 2009.

The universe of the doctorate holders analysed includes three distinct groups, namely: 1) PhDs who earned their doctorate at Portuguese Universities; 2) PhDs who earned their doctorate abroad and requested recognition, equivalency or registration of their degree in Portugal; 3) PhDs who earned their doctorate abroad and made no official registration of their degree in Portugal.

The nominal identification of the PhDs of each of the groups of the universe under analysis, their mobility and professional situation came from distinct sources of information, gathered directly or administratively. Overall, the information was gathered from eight different sources, as follows:

- i) the censitary annual R&D Survey, which is directed towards all entities that potentially carry out research and development (i.e., Government, Higher Education, Private Not-for-Profit Institutions and Companies), including individual information all their researchers;
- ii) National register of ongoing doctoral thesis, which is an annual survey made to all higher education institutions collecting data on ongoing and finished doctoral thesis, with information on the individual, institution(s), field of science, supervisor(s) and abstract. This survey feeds annual information to the dataset of all PhDs whose studies were earned at or recognized by Portuguese Universities since 1970;
- iii) Careers of doctorate holders survey (i.e., CDH), which is a statistical operation that collects information on the categorisation of the PhDs, their academic training, professional situation, international mobility and their scientific production;
- iv) Biographical record of teachers of higher education, which collects annual information on faculty composition of all higher education establishments;
- v) The employer-employee matched dataset collected annually by the Ministry of Labour and Social Security (i.e., "*Quadros de Pessoal*"), with information on firms, establishments and

- workforce, including individual information of 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 includes 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 with reference to; Post-doctorate fellowships financed directly by FCT; Post-doctorate fellowships and contracts of PhD researchers financed by scientific research projects supported by FCT; PhD researchers contracted by Associate Laboratories and research units supported by FCT (specifically in the period 2007 - 2009);
 - viii) Administrative information on teaching staff of non-tertiary education institutions, gathered through the services of the Ministry of Education.

After the process of data gathering 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 the different sources were searched through detailed internet surveys, thus recovering information for a small number of individuals. Still, 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 the full set of doctorate holders identified, which indicates a measure of 'brain gain' for Portugal in 2009. Out of a total of 19,876 PhD holders, only 669 were found to be working abroad (i.e., 3.4%), while 1,836 foreign PhDs were working in Portugal. It should also be noted that about 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.

[INSERT TABLE 1 HERE]

In addition, the data shows that the large majority of the PhDs who earned their degree at Portuguese universities since 1970 was involved in R&D activities in Portugal (86%), mostly in higher education and research institutions. It represents a total of 17,010 doctorates. Of these, 13,888 PhDs were developing professional activity in the public and private higher education sector, while 2,427 PhDs were researchers in the private sector, and 695 were working in R&D in State laboratories and other public entities. In addition, only about 4.5% of the total number of doctorate holders were not performing R&D activities, and 3.3% were retired [21].

The majority of the PhDs whose degrees were earned abroad and recognised by Portuguese universities between 1970 and 2008 are working in Portugal (76.3%), also mainly at higher education and research institutions. Of those PhDs, 313 were foreigners. Additionally, 1,523 foreign PhDs were identified as working in R&D activities in Portugal in 2009, although they did not request their degree to be recognised by a Portuguese University.

These results exhibit the following flows of PhDs in terms of the entry of foreign nationals in Portugal. A total of 1,836 PhDs were identified as either foreigners or whose doctorate was earned exclusively abroad and they were working in Portugal in 2009. It should be clear that this value is underestimated, because 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.

In terms of the migration of Portuguese to other countries, a total of 669 PhDs with degrees earned at or recognised by Portuguese universities were identified as working abroad in 2009.

These results show a positive flow of PhDs into Portugal (i.e., “brain gain”), above all based on active researchers working in institutions of higher education or in private research institutions. In order to better understand these results and to contextualize them in terms of the Portuguese evolution, it should be noted that the country had overcome a gap in scientific and technological development that

had plagued Portugal for decades, indeed centuries, to surpass the average OECD level in terms of researchers per thousand people in the workforce [18].

That small statistic -- going from 1.5 full-time researchers per thousand in the workforce in the late 1980s, to 3.5 in 2005, to 8.2 in 2010 -- begins to tell a very important story about how countries and regions can compete and level the playing field in the dynamic global economy. At the same time, the tertiary education system has been reformed, the social basis for recruitment of students has been enlarged and industry-science links have been strengthened, together with increased 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 experienced the creation and nurturing of opportunities for research and advanced training through strategic partnerships with leading partners worldwide. They cover diverse areas, from deep-sea biotechnology in the North Atlantic to the internet of the future, and involve building further competencies in the nano- and bio-sciences, 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 the explanatory background on how Portugal achieved a brain gain of doctorates can be further analysed from figures typically drawn from various reports produced by the statistics office for science and technology. We start by the scientific output of Portuguese research institutions in all scientific fields⁴, which reached 10,081 publications in 2009, from 6,450 publications in 2005, and just 3,792 publications in 2000. Also, that scientific output, as measured by the number of internationally refereed scientific publications⁵ reached 7,470 articles, letters, notes and reviews in 2009, up from 2,702 article, letters, notes and reviews 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 people in 2009, from 373 in 2004; iii) the number of articles by

⁴ 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.

⁵ As measured by the Science Citation Index, SCI, in relation to scientific publications in the fields of exact, natural, and health sciences, as well as agriculture and engineering.

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 figures above reveal the outcomes of public policies fostering the accumulation of investment in people and institutions. They reflect the growing number of researchers in Portugal that reached about 8.2 per thousand workforce in 2010 (i.e., about 46,000 full time equivalent researchers, FTE, nearly a quarter of whom are 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 encompassing as in recent years Portugal had the highest percentage growth rate in Europe in terms of the total number of researchers (measured in FTE) per thousand workforce (about 95%), well above the European average (which only grew by 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 centres (12,000 doctorate researchers FTE) and a doubling of the number of doctorate researchers since 2000.

The distribution of researchers (headcount) has also increased in all scientific areas since 2005. In 2008, 69% of the total researchers in Portugal were performing research in the aggregated scientific areas of 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 remains relatively low compared with other European countries and US States. Even so, Portugal can count on more doctoral awards per year than some comparable American States, such as Florida or New Jersey, having reached that position from a very weak starting line. Twenty years ago in 1990, Portugal turned out a mere 0.68 new PhDs per ten thousand labour force [18].

4. Time evolution - Learning from an evolutionary path

This section makes use of historical data for the last four decades, in a way to help understanding 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

Figure 1 quantifies the number of doctorates earned or recognised annually at Portuguese Universities, between 1970 and 2008. While this number was below 100 in 1970, it surpassed 1000 doctorates per year by 2003 and 1500 doctorates by 2008. Between 2000 and 2010, the number of doctorates grew more than 74%.

Figure 1 also shows the increasing capacity of training PhDs at a national level by an increasing number of universities. Until the late 1970s only the four oldest universities – University of Coimbra, Lisbon, Porto and Technical of Lisbon - had the capacity to award doctorates, even though the universities created in the early 1970s were also entitled to do so. After about 40 years, 50% of all the doctorates awarded in Portugal are obtained at the oldest universities, in a way that 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 if its share *vis a vis* the total number of new PhDs is increasingly lower, which remits for the evolution of the system in terms of its evolving capacity to train PhDs.

[INSERT FIGURE 1 HERE]

Figure 2 quantifies the ratio of PhDs obtained abroad in relation to PhDs obtained in Portugal. While in the early 1980s the number of doctorates earned abroad and recognised by Portuguese universities was similar to the number earned at Portuguese universities and about two hundred doctorates per year, in

the last decade the capacity for earning doctorates in Portugal rising considerably, surpassing 1300 new doctorates in 2008. On the other hand, along the period under analysis, the number of new doctorates per year obtained abroad and recognised by Portuguese universities has been kept near constant.

This is revealing of two main aspects with policy implications. First, until the mid-1980s the Portuguese higher education system did not have the capacity to train doctorates in general, and there was a clear lack of critical mass in many scientific areas. Second, mobility at doctoral level was assumed as a policy strategy to create the foundations of scientific basis in Portugal upon the return of the doctorates, but also as a means to internationalize the Portuguese scientific and academic communities [25].

In the Portuguese case, there are several universities where disciplinary areas were created or fostered by Portuguese doctorates that 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 Figure 2), but also on fostering internationalization and integration of Portuguese science into global networks of research [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 has echo in other countries, such as in 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].

[INSERT FIGURE 2 HERE]

Considering the annual numbers of new PhDs in relation to the work force of the country, Portuguese universities graduated 2.7 new doctors per ten thousand in the active work force in 2008, while about twenty years ago, in 1990, Portugal produced only 0.68 new doctors per ten thousand active workers. In comparative terms, the state of Massachusetts (USA), Switzerland, Slovakia, Sweden and Finland produced more than twice as many doctorates per ten thousand active workers in 2008. Particularly revealing is the number of new PhDs per ten thousand active workers in the state of Massachusetts

(7.6), or in Switzerland (6.8), which practically corresponds to three times the number in Portugal. Still, Portuguese universities granted more doctoral degrees in 2008 than some North American states, such as Florida or New Jersey, having reached this position starting from numbers that were very low until about ten years ago.

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

It should be noted that the growing qualifications of the academic staff have naturally been achieved under 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. We argue this has been a necessary condition for institutional building, although it is usually referred to in the literature as nefarious to research productivity and collaboration [30]. Although this has also been acknowledged in the last OECD’s 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], it should be noted that “academic inbreeding” is the most obvious solution in any development process, while the science base is weak and until getting an adequate level of maturity.

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

The analysis of this figure, however, is particularly relevant when considered together with Figure 2, in the sense that academic inbreeding levels start to increase when most PhDs start being performed in Portugal. The issue for policy is to what extent the universities have the ability to change academic

recruitment practices that are strongly rooted into 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 Figure 3 do not consider doctorate researchers independent of traditional faculty careers. Those doctorate holders have been critical for the development of the Portuguese research capacity and the increasing scientific productivity of most research units and institutes, despite their transient and precarious labor positions [31]. It is clear that they are prone to move from one institution to another and help decreasing inbreeding levels in the oldest university schools [32]. This suggests the need for further policy instruments directed towards their integration into the academic staff, namely in a way to help renovating the oldest institutions.

[INSERT FIGURE 3 HERE]

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 speeds of evolution at institutional and disciplinary fields. For example, Figure 4 quantifies the qualification of the academic staff of the faculties of medicine, engineering and law in three different universities and suggests distinct institutional and disciplinary paths. On average, engineering faculties have been the fastest in adopting the PhD track for their staff, while faculties of medicine have the qualifications of their academic staff either stagnated or decreasing. This certainly remits our analysis to universal disciplinary cultures, norms and *habitus* [33], although the Portuguese case is also explained by different levels of engagement in research [34].

[INSERT FIGURE 4 HERE]

4.2 Development patterns 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 unfolding of the Portuguese S&T system since the early 1970s and its relationship with higher education and, in general, the Portuguese society, may be discussed based on four main periods, as described in Table 2. Suffice is to say that the effective establishment of the S&T system took place only after independent and international research assessments have started in the mid-1990s. In this respect, the first decade of the 21st century consolidated and strengthened earlier policies associated with a vigorous public investment in R&D, together with a strong drive towards internationalisation.

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

[INSERT TABLE 2 HERE]

1970-1985: early attempts to growth, with 50% PhDs abroad and brain drain

The National Committee of Scientific and Technological Research (i.e., “JNICT - Junta Nacional de Investigação Científica e Tecnológica”) 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. It followed the “Regional Mediterranean Project”, which had focused on the conditions of education in Portugal and other southern European regions. But, by that time, the overall expenditure in 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 in the search for knowledge, a major education reform was launched in 1973 (i.e., the so-called “Veiga Simão Reform”),

laying down the foundation for growth of the Portuguese science base. Grounded in an expanding higher education system, including the creation of new universities, this reform was shaped by a legal enactment to recognise the equivalence of doctoral degrees obtained abroad and to restructure 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 be carried into effect in 1979 when the Statute on the careers of academic staff in universities took effect. It 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 effectively to be set up in universities. As a pointer to the nascent dynamism thus unleashed, between 1967 and 1986, overall expenditure in R&D rose only from 0.25% to 0.36% of GDP. In 1982, across all subject areas, the country mustered 5,736 research personnel and 9,258 by 1986.

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

Integration into the European Union came as a very important opportunity for Portuguese S&T development. The period 1986 to 1989 saw science policies guided by a more complex model of technological change and a growing intensification in international cooperation, including membership of international organizations such as the *Centre Européen de Recherche Nucléaire*, CERN. Under the leadership of Jose Mariano Gago, JNICT's President at the time, a "Mobilizing Programme for Science and Technology" helped defining and implementing a set of S&T priorities and projects in specific areas. In the early 1990s, a number of new programmes were implemented, as supported by European Structural Funds, including a major initiative of individual research fellowships [25]. The CIÊNCIA Programme, between 1990 and 1993, promoted advanced training and the build up of physical infrastructure. Under this programme, 3,204 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 naturally characterized by academic inbreeding in the oldest universities, while “university-science relations” played a significant role to help 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 and the second lowest figure amongst 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, for hiring research staff.

1996-2005: Struggling towards the European average, promoting brain circulation, still with inbreeding

In 1995, the in-coming Government created the Ministry of the Science and Technology, led by José Mariano Gago, a move that involved profound changes to 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 exercise of R&D units, consisting of international reviewers and in association to funding for research, guaranteed the independence and effectiveness of research evaluation, the publication of the methodologies employed and the results obtained, together with the right of appeal. Investment in science increased significantly. For example, publicly funding for university-based research units raised 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, but still far from the European Union average of 1.74%.

The evaluation exercise of 1999-2000 confirmed that successive evaluations 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, still with strong paths of inbreeding at leading institutional levels [37]. The steady increase in the number of doctorates, as considered against European and international statistics, was seen by the majority of evaluation panels as decisive in upholding critical mass in scientific development. Even

so, in the year 2000, the number of research staff plotted against the active population still remained about half the European average – respectively 2.9 and 4.9, for every thousand inhabitants.

2006-2010: fostering knowledge-integrated communities, 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. It broke with the earlier pattern of relatively sluggish or fluctuating investments. It reached unprecedented levels of development.

Above all, the impact of the build-up across two decades of public funding for the advanced training of human resources and laying down new scientific institutions started to bear fruit. Particularly clear was the impact on qualifications and on modernising 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, amongst which Italy and Spain, with 1.26% and 1.39% respectively [38]. At the same time, the share of business expenditure in the 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 1,300 million Euros in 2009.

The recent speeding up in the development of the Portuguese S&T system went hand in hand with its capacity to attract and train human resources. It clearly bolstered the critical mass factor in academic institutions. It launched “new” provision which concentrated researchers across disciplines and built-up knowledge integrated communities with an increasingly marked international outreach. Thus, in Portugal research staff expressed as the number of researchers per thousand employees in the labour force, reached the OECD average. In 2009, this stood at 7.9 per thousand, a level similar – even higher in some cases – to 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 for the design of science policies in emerging regions worldwide. The data used provides a dynamic approach to the cumulative process of attempting to build knowledge-based societies, showing 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 international levels of investment in science and technology and to overcome a situation of continuous lagging behind the international scene. We argue that other regions worldwide may accelerate this process, if adequate policy measures are systematically taken 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 to the specific programs on human capital formation, including initiatives to promote scientific employment. Also, specific policies and instruments to foster research capacity through institutional building are discussed. In addition, the need to promote science awareness at large 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

At the onset of the 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%. Figure 5 shows that there were three main periods of investment growth, with different intensity (1986-1992; 1995-2002; and 2004-2011), as separated by periods of stagnation or reduction (1980-1986; 1992-1995; 2002-2004), while Table 3 briefly characterizes the focus of policy instruments throughout each of these periods.

In the first period of growth the GERD as a percentage of the 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 still to be performed abroad.

In the second period of growth, from 1995 to 2002, GERD as the percentage of the GDP grew by about 50% and new policy instruments were introduced, including postdoctoral fellowships, the external and independent assessment of research units with funding implications (as based on three-years contracts), deemed as decisive for the consolidation, articulation and modernization of the Portuguese research system, and the creation and funding of large research laboratories with ten-years contracts (i.e., the so-called “Associate Laboratories”). From this moment onwards, public policy upheld international research assessment exercises as a regular practice, assessing the output of scientific establishments, and concentrating on increasing “critical mass” of doctoral researchers across disciplines and institutions. Sustained importance was laid on creating job openings in science to bring new blood into the science domain and enhance 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 steepest investment in science. By 2009, the GERD as a percentage of the GDP doubled, mainly through the existing policy instruments, although enlarged through additional public funding. The number of “Associate Laboratories” was extended, and a few new policy instruments were considered. These included a major program to foster scientific employment through doctorate researchers with five-years contracts, a program of Research Chairs and a program of international partnership with prominent research universities and institutions worldwide.

[INSERT FIGURE 5 HERE]

[INSERT TABLE 3 HERE]

As a result of the accumulation of public investment, the last few years saw the emergence of three distinct, but inter-related trends. First, a remarkable increase in overall business expenditure on R&D (BERD) and in industry's capacity to undertake research in collaboration with academic research centres. BERD rose from 425 million Euros in 2005 to over 1,300 million Euros in 2009.

Second, the relative spread across the number of firms investing in R&D. This grew 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 comes as a "green light" in the overall goal of raising and sustaining the business sector's participation in the national drive to increase technological intensity in the Nation. Yet, analysis also suggests that large companies certainly need to increase their R&D investment significantly, if science-based job openings are to increase in the business sector and if further specialisation in the skills required by these emerging areas is equally necessary if both are to advance.

Third, a considerable increase in academia's research capacity, with the number of PhD fellowships and post-doctoral research contracts rising more than two fold. Nevertheless, although the impressive increase in the investment in R&D in recent years, it 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 a slow –often-intermittent – move 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, the level of Portugal's accumulated science investment over the past few decades was not even close to the level in those countries. Building up the nation's scientific development to a position similar to the countries just mentioned requires both a far larger and sustained investment in science, at a rate faster than those countries and over a long period.

Second, despite the investments in S&T for the periods given, Portugal is still far from the investment levels of other small and medium sized countries in the European Union, such as Belgium, Austria, Denmark or Finland, for instance. One indirect consequence of these two features is the persistent “infantile status” in industry-science relationships and the present ‘immaturity’ in both industry and academia to plan joint ventures over the long term. This is certainly affected by the structure of business enterprises, as well as by the lack of large companies in sectors traditionally involved in advancing these ties in other industrialised countries.

5.2 Advanced training of human resources and human capital formation

Creating and augmenting critical mass is vital for the creation and dissemination of knowledge, and attaining that critical mass is of the utmost importance both for developed and developing countries, but a focus that is particularly relevant for emerging regions worldwide. It is in this context that our main lesson from the evolution of the Portuguese research capacity towards a level characterized by a notable brain gain of advanced trained human resources considers a major, long-term public funded and centralized program of research fellowships. In addition, it should be noted that it has been continuously promoted along the last decades upon independent national evaluations of individual proposals, in a way totally independent of any higher education institution.

Four main facts are discussed below, namely: i) the required accumulation along 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 a post-doctoral level and in a temporary basis; and iv) the reality of academic inbreeding in the oldest universities.

Figures 6 and 7 quantify the large public effort on the advanced training of human resources and on providing research oriented careers, on a temporary basis, giving the ability to recent doctorates for developing research in a rather independent fashion.

[INSERT FIGURE 6 HERE]

[INSERT FIGURE 7 HERE]

Almost 14,500 doctoral fellowships and more than 4,500 postdoctoral fellowships were awarded through a centralized program of individual grants from 1995 to 2008. All of them considered an option for a research or learning spell abroad, with varied intensities ranging from three months to full time abroad. This favoured the mobility of researchers and the growing internationalization of the Portuguese research staff and academia [25, 39]. Analysis clearly shows a gradual change throughout time in the mobility patterns, with decreasing number of fellowships fully spent abroad [32].

It should also be noted that, for last fifteen years analysed, foreigners were awarded with more than 1,100 doctoral fellowships (8% of all the doctoral fellowships awarded) and more than 1,500 postdoctoral fellowships (33% of all the postdoctoral fellowships awarded) to perform their doctorates at Portuguese universities or to engage in postdoctoral research activities. This has been a strategic asset in the international competition for talent and follows many other national strategies at a world level (see, for example, the Science fellowship program in Japan, as discussed by [5]).

Our analysis also shows the importance of public policies facilitating, and imposing, scientific employment through a research career path in universities. This was established beyond traditional faculty 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, the 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 centres and Laboratories.

Figure 8 shows the related levels of employment of doctorates in higher education, leading to the following main aspects. First, about 1,200 new PhD researchers with more than 3 years of postdoctoral experience were hired by 2009, of which 41% were foreigners. Unlike the internationalization of the student population at Portuguese universities (which relies on nationals from Portuguese Language

Countries, [39]), the internationalization of the research community shows the prevalence on nationals from the European Union and from all over the world, with nationals from Portuguese Language Countries only accounting for 4% of all the research contracts awarded. The hired PhD researchers were based at 264 research units in all areas of knowledge (with some 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 still with minor implications in faculty positions. The number of foreign academics in the Portuguese tertiary education system totalled 1,400 academics in 2009 (an increase of 26% since 2001). Additionally, the number of foreign researchers almost doubled, from nearly 1,900 in 2005 (6% of the total number of researchers) to about 3,800 in 2008 (7% of the total).

[INSERT FIGURE 8 HERE]

Still in relation with human capital formation, our analysis reveals the importance to consider academic inbreeding at regional, or institutional levels (i.e., micro levels) for some time periods, in order to build the necessary “absorptive capacity” those regions and institutions need to acquire. This is a learning process that requires the accumulation of critical masses in academia. The need to quickly building-up research and teaching capabilities at early stages of development lead the oldest universities to hire their own doctorates, with evident short-term benefits for both.

Once those universities attain maturity they tend to assume a monopolistic position as the main producers of doctorates [40]. Inbreeding rates at other universities are never as prevalent compared to the oldest universities because they are created at later stages of development, and on a first stage of development they employ PhDs from those old universities. However, as these more recent universities struggle to achieve an elite status and build-up their research and teaching base, they look at the development of the oldest universities as a role model, and the same model of development tends to be

replicated. This leads to academic inbreeding practices at these universities as a way to foment their own institutional tradition, culture and socialization [24].

In this process, it is important to realize that academic inbreeding practices brings key features that are critical for the process of institutional building, such as the reinforcement of organizational/institutional academic cultures, the consolidation of research agendas and guarantee organizational stability [24]. These features determine the needed stability for the universities to grow in the early and middle stages of their development. The challenge is to limit this practice when it changes from beneficial to detrimental. The stability that academic inbreeding brings turns over time into organizational ossification, intellectual inertia, and parochialism, that clashes with current societal needs where universities are required to respond to increasingly varied and complex issues [41]. As Figure 3 suggests, this is a particular challenge for Portugal that is reaching an early maturity stage of development and for other countries and emerging regions around the world (academic inbreeding rates are rampant in Asian, South American and African countries for example [42, 43, 44, 45]).

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. Under this context, a key policy instrument in the Portuguese case was a public program to fund research units based on multi-annual contracts established upon 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 relevance of the national research assessments in Portugal in terms of a substantial growth of the number of R&D units, but above all to the doubling of the average number of PhDs in each R&D unit. This facilitated critical masses at the institutional level, with clear impact in terms of the number of articles in international peer review journals and increased scientific related networking at national and international levels [46].

[INSERT TABLE 4 HERE]

The growth in the number of PhDs at the R&D units, a large part of them based or associated to universities, has been established independently from traditional faculty careers and of internal university procedures, but rather based on a recruitment that follows the best international practices. Figure 9 attests this by showing that the employment of doctorates in higher education has been following this trend, as universities also seem to be unable to absorb the new doctorates into the traditional academic staff.

This has been evidenced more clearly since 2003, a time when the number of new doctorates per year overpassed the 1,000 mark. Although in the short term this is sustainable – as long as there is funding available through postdoctoral fellowships and PhD research contract grants for a substantial share of the doctorates in the scientific system – in the middle and long turn this will potentially may lead to a situation of brain-drain [47]. As discussed before, this entails policy instruments towards fostering scientific employment throughout the labour market, with emphasis on industry [see also 48, 49, 50, 51].

[INSERT FIGURE 9 HERE]

A landmark in terms of institutional building in the Portuguese research landscape was the setting-up of “Associate Laboratories” in November of 2000, through long-term contracts with the Portuguese Science Foundation (ten-years, in contrast with three-years contracts with typical research units). By 2001, 15 laboratories were active, bringing together 31 research units and more than 2,200 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 eighty million Euros, compared with five million Euros a decade earlier.

One of the main objectives assigned to Associate Laboratories called for an increase in scientific employment by recruiting both doctorate researchers and additional technicians. As a result, the average number of PhDs in Associate Laboratories is twice that of general R&D units. A second objective set out to develop critical mass in each and 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 evaluation, a culture that had been developed and implemented in both the OECD countries and in most established and mature science systems [52].

At this stage, by 2005, the process of institutional building has been oriented towards better articulating the research system with higher education institutions and private companies, while at the same time fostering forms of institutional internationalization, in addition to a considerably good level of individual internationalization of the science base. This was performed through establishing selected partnerships with world leading research universities and institutes 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 formed through the Portuguese Science Foundation, unprecedented in Portugal and with innovative features worldwide. They have opened the way for setting up a number of thematic networks with industry and across various Portuguese universities. In addition, these programs have been strategically important on impacting doctoral education and advanced studies programmes, some of which were offered as dual degrees between leading US universities and Portuguese universities. Also, in integrating academics and researchers in application-driven, collaborative research projects oriented for markets worldwide [22].

[INSERT TABLE 5 HERE]

Overall, the influence exerted by incentive-based funding programmes in promoting R&D was both self-evident and decisive. Even so, different forms of incentives need complementary action to raise both R&D intensity and scale. Contract research was particularly important. If research is to assume a new dynamic, other incentives have to be brought to bear. And private sector firms, in particular, require other forms of encouragement – for instance, tax breaks for those actively engaging in research and innovation. In short, priority in developing the science system rests on a variety of incentives.

5.4 Remaining challenges

Our discussion above is centred in building research capacity through people and institutions and we conclude by briefly introducing further challenges in the development of the intensity of the research investment. This is important in the sense that it quantifies long-term stability of a research system, as well as helps deepening our understanding of diversified forms to promote the development of a science base.

Figure 10 shows that in the case of Portugal (also Slovakia), the growth of the research system followed a path of relatively low (and, some times, decreasing) levels of funding per researcher, in a way to give absolute priority to the need to attract people and build critical mass. Our results show the success of such strategy, even in an international landscape increasingly characterized by high level of competition towards talent. Nevertheless, it is interesting to note that other countries in different national and international contexts, such as Spain or the Czech Republic, followed slightly different patterns, achieving increased 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, is that our results show that it is possible to grow a research system with relatively low intensities and still be attractive to potentiate a situation of brain gain.

[INSERT FIGURE 10 HERE]

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.

The main data refers 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, by the end of that period, a notable process of brain gain, which is discussed in terms of a new contribution for 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 favour of a few major counter-intuitive measures and science policy instruments, as follows:

1. A central finding is that public investment in science associated to 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 the international scene. 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 other regions worldwide may accelerate this process, if adequate policy measures are systematically taken 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 attractive enough to foster brain-gain;
2. In addition, our research suggest the key role of a major, long-term public funded and centralized program of research grants, namely for doctoral and post-doctoral grants upon independent national evaluations of individual proposals, in a way totally independent of any

higher education institution. We argue this is particularly important to be implemented at earlier and middle stages of development to avoid the investment to be absorbed by hierarchically and change-adverse environments that characterize many higher education institutions in developing regions;

3. Also, our analysis shows the importance of public policies facilitating a research career path in universities, independent of traditional faculty careers, in a way that facilitates the continuous recruitment of young researchers by academic research units following best international practices, but independent of internal university procedures. It is clear that the relative transient and precarious nature of that research career path, leads us to argue for the need of integrative measures facilitating gradual recruitment policies by the public and private labour markets;
4. The data reveals the importance to promote academic inbreeding at regional, or institutional levels (i.e., micro levels) for some time periods, in order to build the necessary “absorptive capacity” regions and nations need to acquire. This is a learning process that requires the accumulation of critical masses in academia;
5. Last, but not least, a public program to fund research units based on multi-annual contracts established upon national research assessments, also totally independent of internal university hierarchies, help building the necessary institutional capacity towards knowledge-based societies. This is again a long-term process, requiring different institutional speeds and types of multi-annual contracts;

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

In attempting to extrapolate our results for 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 stage careers. In addition, we argue that science policies emphasizing the advanced qualification of human resources, together with democratizing the access to science, help building the necessary conditions driving modern societies.

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1. Doctorates (PhDs) awarded by Portuguese universities between 1970 and 2008	14147
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	2.5%
2. Doctorates (PhDs) awarded abroad and recognized by Portuguese universities between 1970 and 2008	4206
With Portuguese nationality	3491
With a non-Portuguese nationality	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	6.9%
3. Foreign Doctorates (PhDs) which performed their Phd abroad and did not register it in Portugal or that are developing R&D activities in Portugal (in 2009)	1523
Flux of doctorates:	
Number of foreign doctorates (PhDs) or with a PhD degree obtained abroad, working in Portugal (in 2009)	1836
3.1 % foreign Doctorates (PhDs) working in R&D-related activities in Portugal (in 2009)	82.9%
3.2 % foreign Doctorates (PhDs) working in non R&D-related activities in Portugal (in 2009)	17.1%
4. Doctorates (PhDs) awarded or recognized by Portuguese universities working abroad in 2009 (1.3 + 2.3)	669

Note: * The maximum expected uncertainty of this analysis is associated with those PhD holders with no identified workplace; Source: GPEARI (<http://www.gpeari.mctes.pt/index.php>)

Table 2 – Main periods/phases considered in this paper about the evolution of science policy and scientific and technological development in Portugal (1970-2010)

Periods	Mobility trend	GERD/GDP	Total researchers (those with PhD)	S&T policy instruments
1970-1985	early attempts to growth, with 50% PhDs abroad; few PhDs in Universities (brain drain); high academic inbreeding	0.28%	5.736 (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 possibility of creating large Associate Laboratories, to foster research excellence through networks of academic research centres; Research career status; promotion of scientific culture and the public understanding of science
2006-2010	increasing capacity; research contracts (towards brain gain)	1.7%	75,073 (23,125)	Scientific employment through competitive research contracts; University Chairs; Renewed University governance and assessment systems; International partnerships promoting thematic networks of research and advanced training; Further promoting the public understanding of science

Table 3– Main science policy instruments used along time in Portugal (1970-2010), as identified in this paper

Public policy instrument	Characterization/focus	Starting decade	Ongoing
Doctoral Fellowships	Centralized program oriented towards the advanced training of human resources, independently of university hierarchy	Late 1960s with JNICT; the number of fellowships and R&D projects increased substantially after 1986, through EU funds and, above all, 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; foster 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 years contracts	Promoting research capacity through institutional building, independently of university hierarchy. Facilitated 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 years contracts	Federation of the better qualified R&D units in the assessment exercise; focus on critical mass and renewal of the researcher's base.	Since 1999	Yes
International partnerships with leading universities and research institutes	Thematic research and advanced training networks, facilitating the internationalization of Faculty; increase R&D collaboration among Portuguese universities; Increase the qualification of the Faculty; Faculty exchange programs and pedagogical and scientific improvements.	Since 2006	Yes
Post-Doctoral research contracts program	Attraction of researchers nationally and internationally with a doctorate with some years of research experience; renewal of the university faculty	Since 2007	Yes
Sponsored Research Chairs	Attraction of Foreign and Portuguese senior faculty to come to Portuguese universities, co-sponsored by firms	Since 2007	Yes

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	11426
Average number of PhDs per Research Unit	13.7	17.4	17.4	27.0

Source: Portuguese Science and Technology Foundation, FCT

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

Program	Launched /signed	Human resources focus
MIT-Portugal	October 2006	<p>Doctoral education: (joint doctoral programmes among Portuguese universities) with research spells spent at MIT in bio-engineering systems, engineering design and advanced manufacturing, sustainable energy systems, and transportation systems;</p> <p>Master programmes and advanced studies programmes in bio-engineering systems, engineering design and advanced manufacturing, sustainable energy systems, and transportation systems;</p> <p>In collaboration with Sloan School of Management, establishment of the Lisbon MBA with Portuguese business schools</p> <p>Creation of an educational consortium involving Portuguese schools of engineering, other associated Portuguese schools (mainly of economics and social sciences), associated laboratories, national public laboratories, industrial research laboratories and MIT</p>
Carnegie Mellon -Portugal	October 2006	<p>Doctoral education: dual Doctoral programmes 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;</p> <p>Faculty exchange programmes bringing Portuguese faculty to teach at CMU, and to learn new pedagogical and curricula perspectives</p> <p>Dual master degrees between CMU and Portuguese universities in entertainment technology, human-computer interaction, information technology/security, and software engineering</p> <p>Post-doctoral fellows in Mathematics (mainly applied mathematics, probabilities and stochastic methods)</p>
Univ. Texas at Austin-Portugal	March 2007	<p>Doctoral education: dual Doctoral programmes with the University of Texas at Austin and Portuguese universities, in Digital Media and Mathematics. Post-doctoral fellows in Mathematics and Digital media</p>

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

	S&T system			
	Total researchers (headcount)		Funding per researcher (1000 US\$)	
	2001	2008	2001	2008
Czech Republic	29216	44240	65.064	71.256
Denmark	29791	48442	124.153	100.758
Estonia	4803	7226	21.203	39.758
Finland	47534	55195	94.804	113.089
France	217173	289478	158.104	127.223
Hungary	28351	33739	41.658	46.654
Iceland	3231	4158	76.981	71.339
Italy	100442	145623	160.582	131.594
Japan	792699	890669	128.280	138.265
Korea	178937	300050	116.172	127.555
Norway	34864	44145	74.268	82.071
Poland	89596	97474	28.456	34.782
Portugal	31146	75073	45.999	39.288
Slovakia	15923	19814	24.417	22.789
Slovenia	6740	10124	79.689	79.827
Spain	140407	217716	57.973	67.975
Turkey	67190	106423	44.475	56.495

Source: OECD

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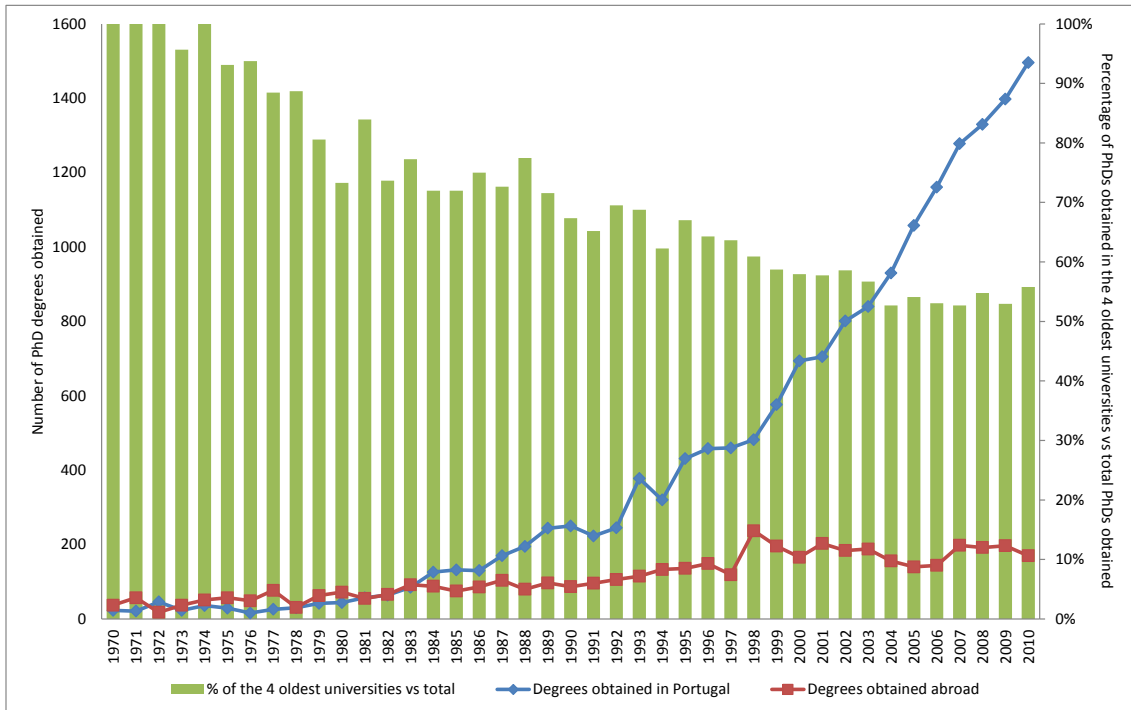
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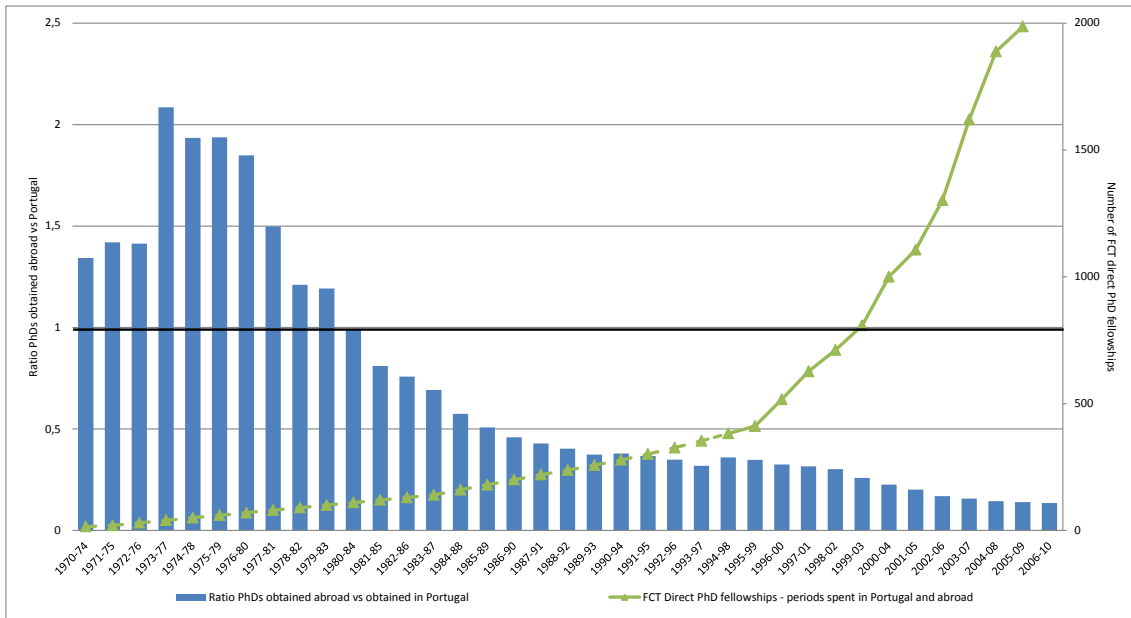
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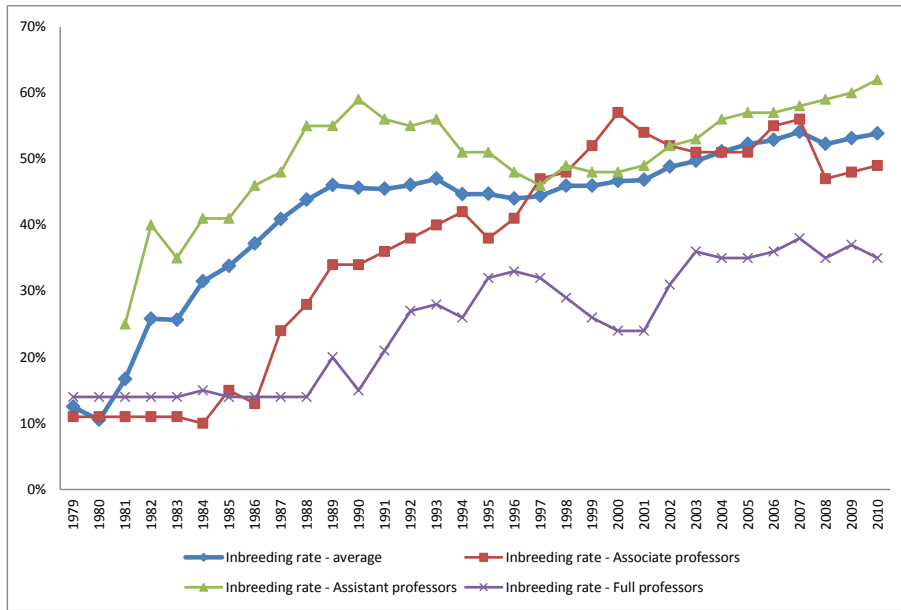
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Note: FCT direct PhD fellowships may involve periods in Portugal and abroad. The trend previous to the quinquena 1994-1998 is simulated

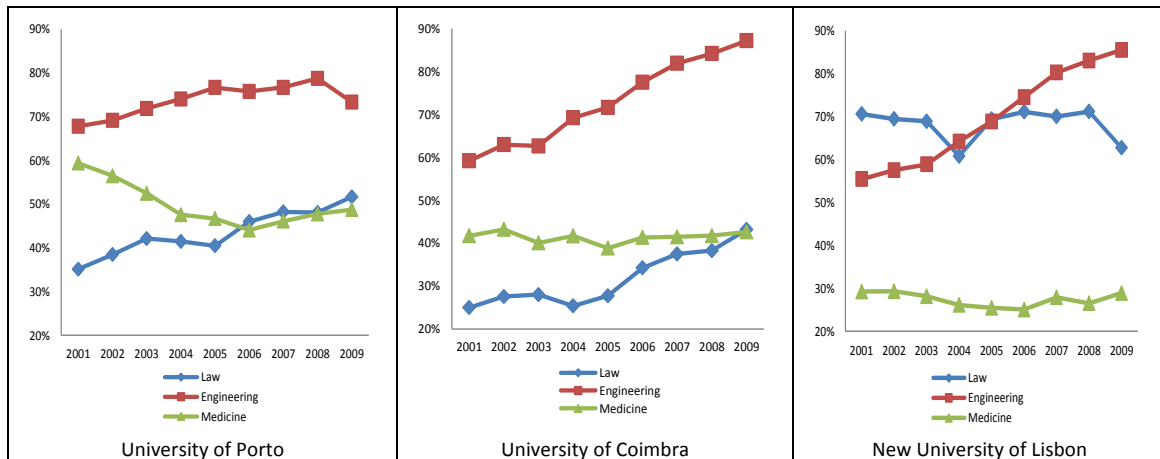
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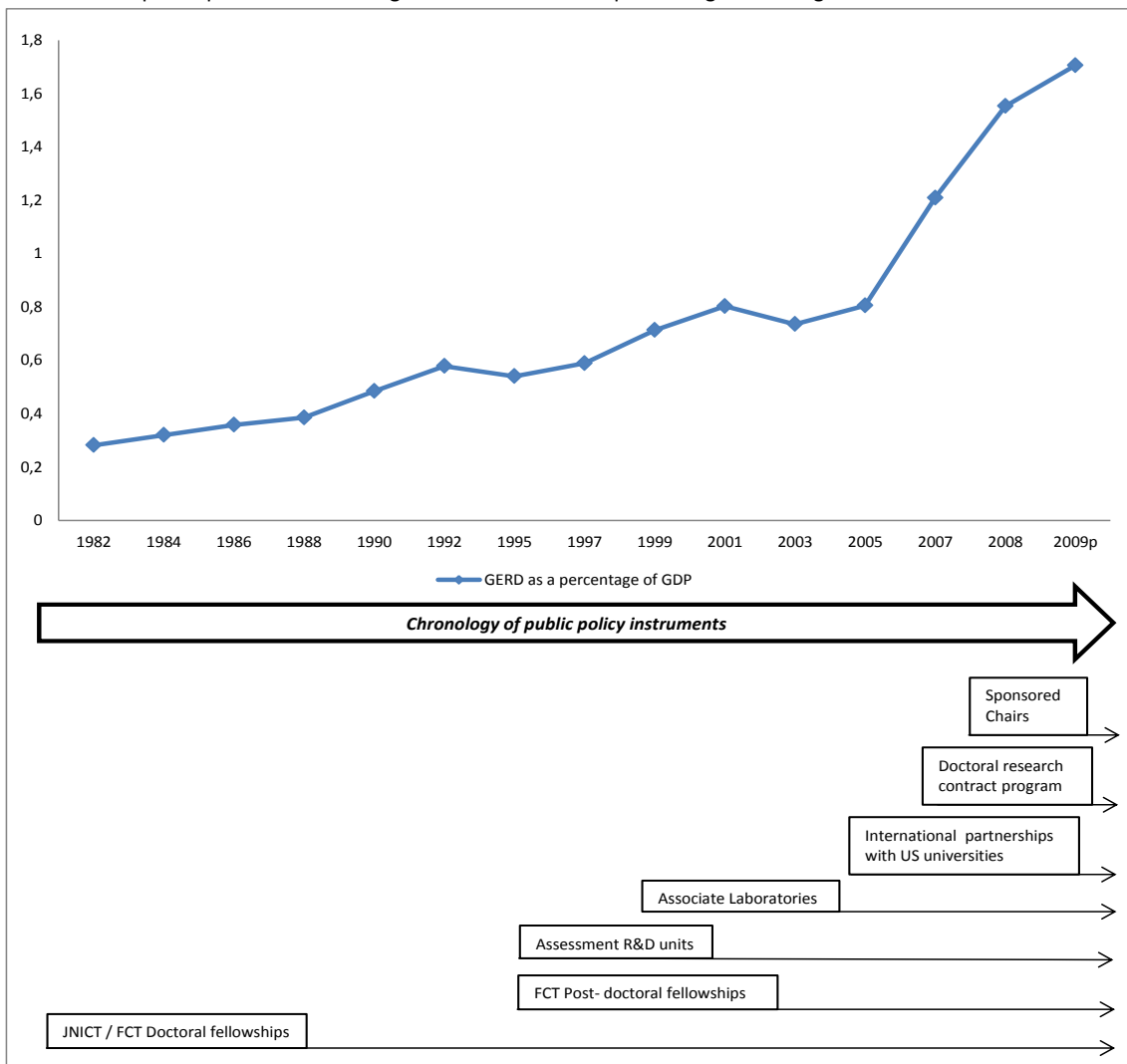
Source: FEUP, University of Porto

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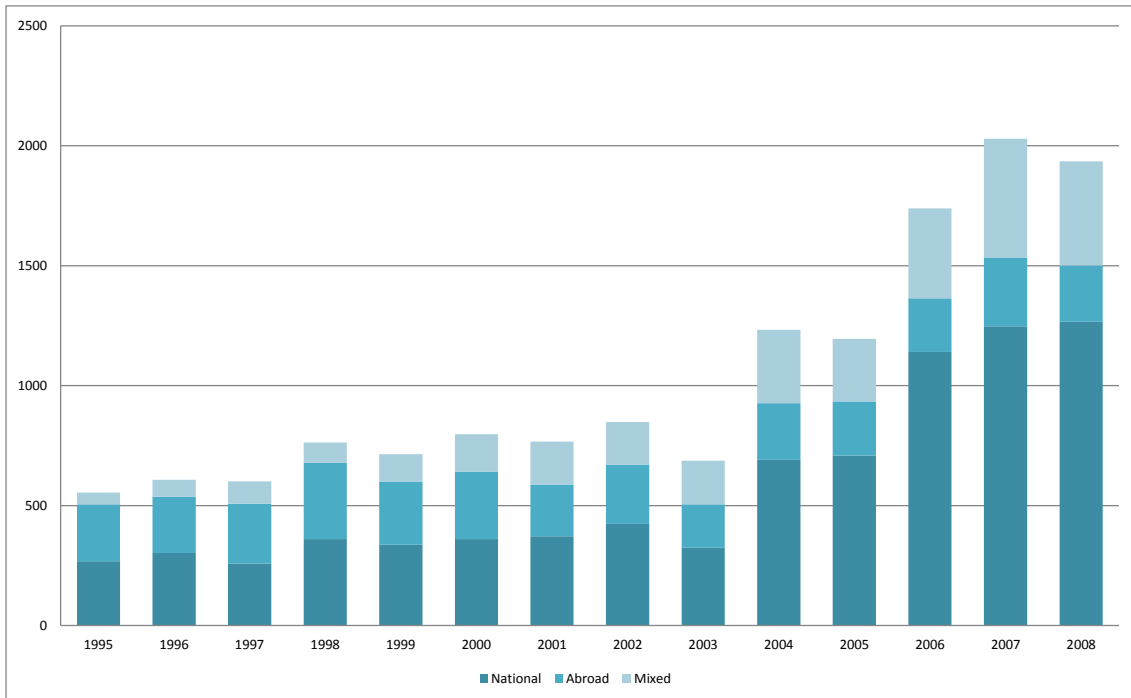
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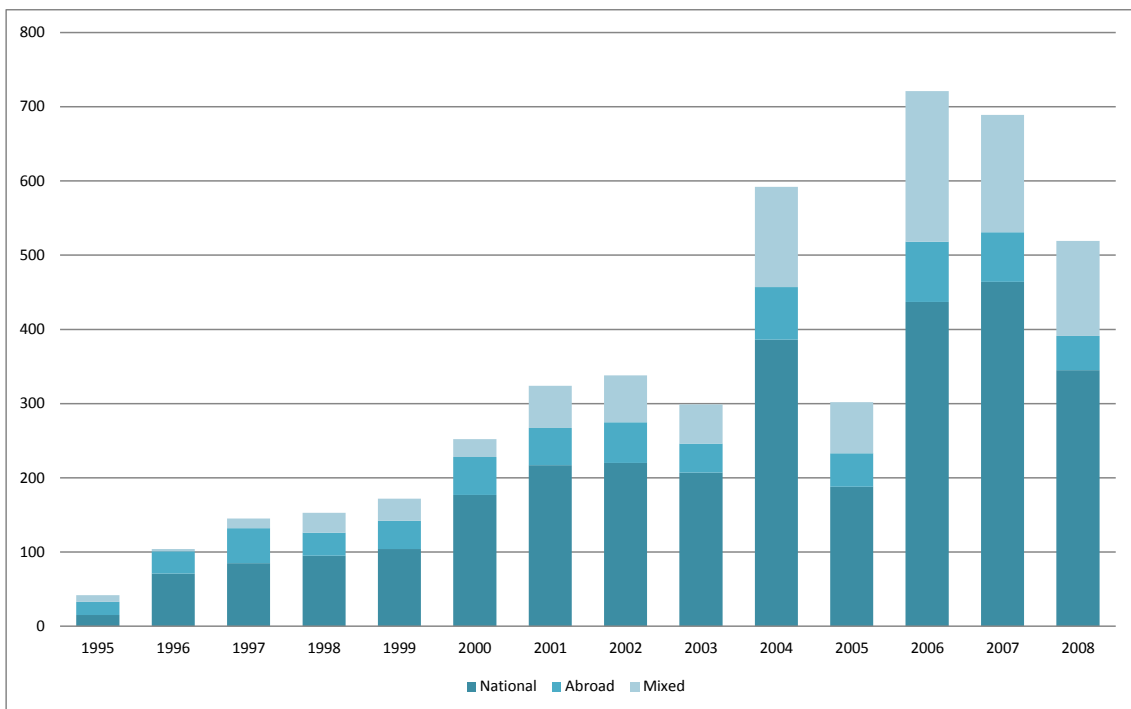
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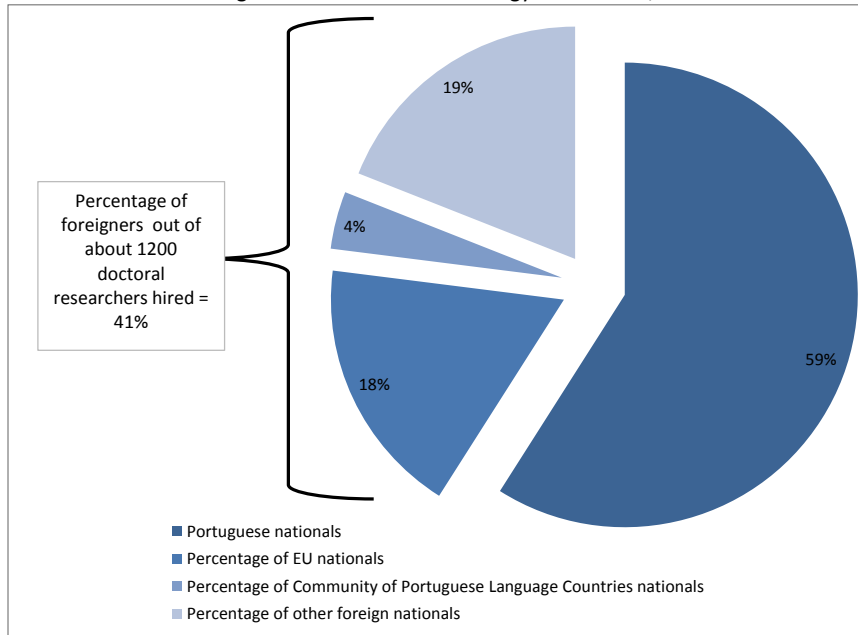
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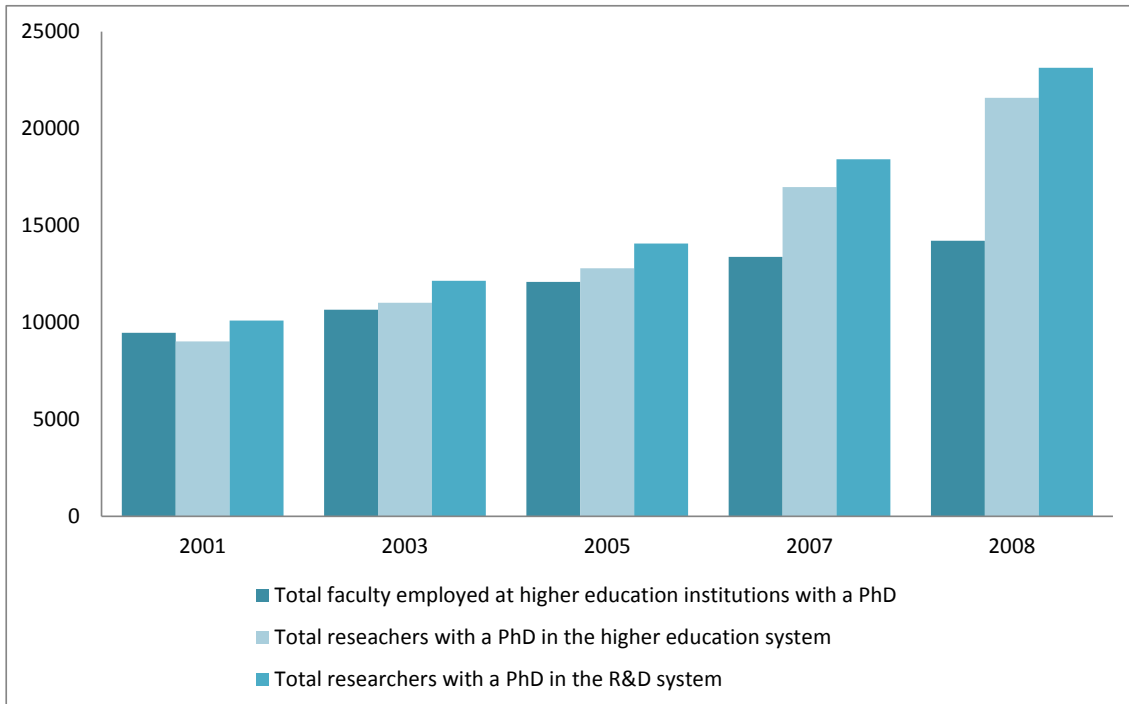
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Note: The total researchers with a PhD in the Higher Education sector include those performing research at IPFSLs;
Sources: REBIDES, GPEARI - MEC; IPCTN, GPEARI - MEC