CREATION AND DEVELOPMENT, FROM THE INDIVIDUAL RESEARCHER TO RESEARCH EMPIRES

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This paper is dated: it was written at the time of the celebration of the 20 years of activity of the Évora Geophysics Centre (CGE). It comprises a brief appraisal of the evolution of scientific research in Europe and in the United States of America, together with a special reference to the development of the Portuguese scientific system. The size distribution of scientific teams in the whole system is addressed, and it is shown that at a state of optimal performance there is room for all team sizes ranging from the individual investigator to research empires. Similarly, we note that research dynamics evolve in time with periods of strong creation intensity that alternate with periods of extension and quiescence. We also note that the new perspectives for the European Research Area, with policies that push strongly to the development side, may be risky in the long term as they might lessen creation, which is the base for sustainability and development. Finally, we briefly address the challenges ahead both for the Portuguese scientific system and the CGE.

1 Introduction

Scientific research, seen as the creation of new ideas that are spread within a community for public use, began with the individual investigator. The celebrated philosophers of Antiquity, Pythagoras of Samos, Euclid and Ptolemy of Alexandria, Archimedes of Syracuse, are examples of people that collected, created and disseminated new ideas in the Ancient World. The new ideas that help us to understand Nature and that might anticipate the knowledge of natural processes are called *scientific knowledge*. From Antiquity to the present time the History of Science comprises many examples of individuals that contributed to creation of the body of scientific knowledge that shapes our current vision of Nature.

The successful ideas last long and shape the context for opinions, judgments, beliefs and actions, namely they become paradigms of knowledge, some of which last for centuries. In our world they provide the ground to develop technologies, decision making, and even to social behavior. Though a new step forward often springs from the individual researcher, the subsequent exploration of the new field of knowledge together with its associated technologic development is a task of a large number people. However, in some rare special cases, namely when huge data collection is needed, the breakthrough comes from a large group of people. This raises the questions of how to balance the role of the individual researchers or the small groups of research in an optimal performing scientific system, and also that of the role of those groups that put more effort on the pursue of new breakthroughs with respect to those whose main work is to regularly extend the knowledge of the working field.

The purpose of this paper is to discuss these two questions in the current Nacional and European frameworks.

2 A quick look on the evolution of the Portuguese scientific system

In Europe, public funding of research activities existed indirectly in the sense that it was carried out in universities and academies that received state funding. This is particularly true for the major European states namely Germany, France and the United Kingdom. From the beginning of the 20th century, foundations have appeared that also contributed to research funding. As Sverker Sörlin [1] notes:"*Some of the largest foundations were started in the US, typically by industrial families and corporations. In Europe foundations were typically smaller, with Wellcome (UK), Gulbenkian (Portugal), and the Wallenberg (Sweden) Foundations as notable exceptions. However, in some European countries the foundations grew quite numerous (Anheier 2001) to make them cater for a substantial proportion of research funding (they never played a major role in the funding of higher education). The foundations were innovative and developed new forms of research funding – projects, programs, centers of excellence, schools of advanced study, specialized institutes – that were later copied and scaled up by public funding agencies."*

In the United States of America, the determinant role of science and technology for the victory of the Allies in World War II was recognized in the Report *"Science The Endless Frontier"* presented to President Roosevelt by Vannevar Bush, Director of the Office of Scientific Research and Development (July 1945) that established the basis for the development of a public funding program of research through the *National Science Foundation.*

In Portugal the governmental body "Board for National Education" (JEN) was created in 1929, which developed in 1936 its specialized office "Institute for High Culture" with the purpose of providing grants to Portuguese scientists to study abroad, and also some support to the few embryonic scientific research groups. In 1950 it became an autonomous office with the name of "Institute of High Culture" (IAC), which was restructured in 1976 to give birth to the "National Institute for Scientific Research" (INIC), which lasted until 1992 when it was extinct. On the other hand, in 1967 the "National Board of Scientific and Technological Research" (JNICT) was created, which accrued the administration of the financing of institutions of higher education and post-graduate fellowships, upon the extinction of the INIC in 1992. The "Foundation for Science and Technology" (FCT) began in August 1997, inheriting functions of JNICT, after its extinction in 1995.

The first Portuguese research teams started either within the university context or were promoted by private entities (e.g. the Gulbenkian Foundation) or else by governmental bodies (e.g., "the Board for Nuclear Power").

In the beginning of the last decade of the XX century, the European programs STRIDE (Science and Technology for Regional Innovation and Development) together with the inter-governmental initiative EUREKA ─ that had the purpose of creating cooperation and synergy research among activities in the European Union, namely the "Framework Programs for Research and Technological Development", and the "European Research Area" ─ provided the support for the national programs aiming at boosting the Portuguese science and technology system, namely: the "Mobilization Program on Science and Technology", the "Basic Program of Scientific and Technological Research", the "European European Southern Observatory", the "CERN Fellowship Program", and the "Program Science, Technology and Society". Many new research units appeared at the time (e.g. the Évora Geophysics Centre, CGE, 1992) covering all fields of Science, Technology, Social Sciences, the Humanities, and the Arts.

FCT started up programs of regular funding together with evaluation of these research units. The funding was provided on an annual basis and accounted both for the rate at evaluation and the number of PhDs of the research unit. In 2012, FCT announced a new funding policy that is aimed to focus on the best rated strategic projects and the objectives accomplished by research units. Networking and reshaping of the actual research units is expected to occur as the right strategy for best positioning for competitive funding.

3 Size distribution of research units and performance of a scientific system

The output of research that is valued socially is the production of new ideas of nature and society, new processes that are reproducible, new technologies and machines that make everyday life easier and safer. Societal valuation is payed back to researchers in the form of social recognition, better salaries, and funding to research. In order to maximize their output researchers collaborate and organize themselves in teams of research.

Two questions arise: (i) Is there an optimal size for a team that seeks to maximize its output? (ii) Will the performance of a national scientific system grow with the size of its research teams?

3.1. *Is there an optimal size for a team that seeks to maximize its output?*

Optimization makes sense only if constraints are present. In the case of research teams the main constraints are the available number of researchers per area of expertise, the funding available on a regular basis, and the facilities made accessible to the team. If some of these constraints is relaxed it can became a variable for optimization to reach maximal research output. For instance, the research team might be in position of optimizing its size in some particular context of funding and facility availability. This objective is achievable because it is possible to find the optimal number of researchers that maximizes the performance of the team in that context.

However, in general, the size of the team evolves in time driven by a multiplicity of factors other than search of optimal performance, the same happening with the team territory (the ensemble of facilities). In this way, any research team may be viewed as an open and lively (out of equilibrium) subsystem with a proper territory (facilities) that exchanges ideas and researchers with the global scientific system.

3.2. *Will the performance of a national scientific system grow with the size of its research teams?*

A scientific system is composed of a constellation of research units of very different sizes that are regularly reshaped due to the main driver that makes the system alive: the social recognition of the research output. In such a system, the individual investigator and the large group coexist in such a way that none of them can get rid of the other, rather they appear entangled and complementary. One might ask if some trend emerges from the internal dynamics that drives the system in a preferential direction, for instance if the large teams are so successful that they tend to be few and larger such that the smaller ones (and the individual investigator as well) will become less and less numerous?

Historically, the national scientific systems have evolved and have been reshaped in time, yet never the smaller research groups neither the individual investigator have disappeared. In fact, those that disappeared were somehow balanced by new emerging research teams. The same move is observed with the larger groups, though at a smaller pace.

Successful models of scientific systems must account both for the cohesion and disaggregation forces that determinate its internal dynamics. A. Bejan [2] provided a beautiful Constructal model of the dynamics of a scientific system that explains in simple form many features of self-organization in contemporary research, namely:

1. *The coexistence of research empires with individual investigators.*
2. *The scaling of the size of the large group with the size of the entire institution.*
3. *The strong relationship between the size and the visibility of the institution.*
4. *The emergence of the first large groups in the largest research institutions of the era.*
5. *In time, as incentives become stronger, small institutions also organize into combinations of large groups and individuals.*
6. *Complete coalescence into large groups is not happenin*g.

As a corollary, he points out: ”*the apparent conflict between research empires and individuals is not a conflict: it is a balance that serves the institution as a whole*” [2].

The above conclusions are rather comfortable to small groups and the individual investigator as well, because they indicate that every team regardless its size might find its place in a scientific system with optimal performance.

4 The trade-off between creation and development

Historically, creation has been assigned to the individual investigator, while development has been a task of research teams. Actually, we can never find creation without development, and vice-versa. Reality is far most complex and science progresses in a permanent trade-off between creation and development.

The great breakthroughs in science and technology usually spring from the individual investigator, while the group is the better arena for the flow of ideas and for synergetic thinking. Indeed, the group is short-lived, works discontinuously as compared to the individual. This one carries for long (years, decades) a continuous and unique internal process of elaborate thinking that enables him to makes inferences, testing and re-elaboration of hypothesis, synthesis, and finally theory. This confers the individual a great advantage over the group, and this is why individuals have generally more success on the creation side.

Usually, the group starts forming around a senior independent thinker that attracts other thinkers/researchers, i.e. investigators to carry out a program of research. Every team member contributes to the common goal, yet each one develops different tasks. As the group gets larger, its preeminence grows because it is able to encompass the study of larger and complex systems, yet this is balanced by the progressive weakness due to every team member is progressively less able to think the system as a whole. This is why creation is less likely to occur, and creation intensity gets smaller as the group becomes larger and larger. Large groups develop research programs, which due to their magnitude cannot be carried out by small teams or individuals, yet creative intensity resides in the smaller groups and asymptotically in the individual investigator.

Hence, the research output results from a trade-off between creation and development (extension). Creative individuals (teams) break the existing frontiers, and inspire others to explore every corner of the new field of research. They drive the whole scientific system in a move to map the new territory by accumulating huge amounts of data, install new settlements (facilities, groups, institutes, etc.) making new knowledge globally available (see fig. 1).

By breaking frontiers, creative teams (individuals) are the real drivers of progress in science and technology. However, the exploration of the new territory is not a task at the

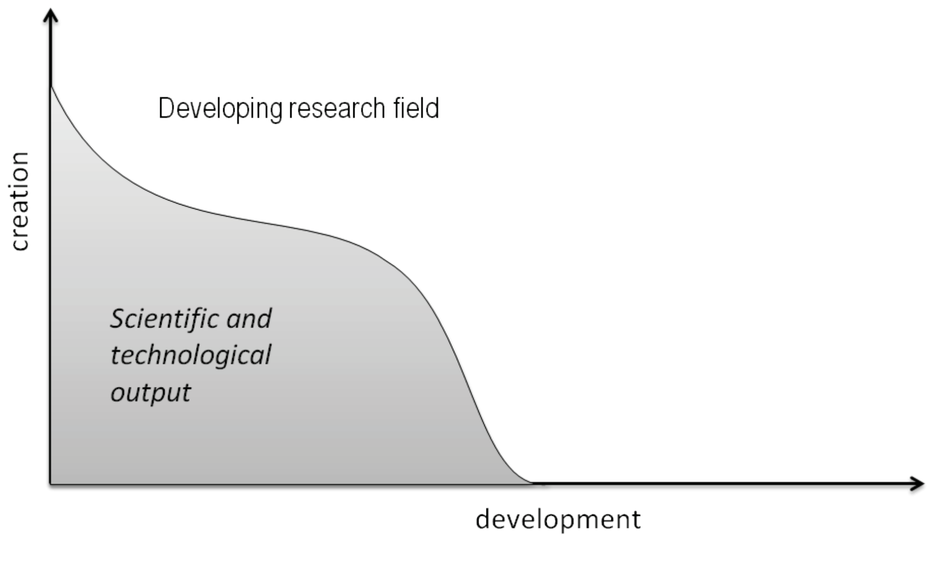

Figure 1. Creation versus development in a developing research field

reach of individuals, and even of most small teams, rather it is a mission that must be undertaken by as many people as those necessary to make a successful journey. It requires organization, a rather long preparation, and funding on a regular basis. Funding is provided to teams at a rate that depends on the economic and social value of their work, and that lasts as long as the research output keeps getting social recognition. In general, exploration of a new field of research initiates at an accelerated pace during some period, peaks at some moment in time, and then decelerates for a longer period, which corresponds to its quiescent state (See fig. 2.)

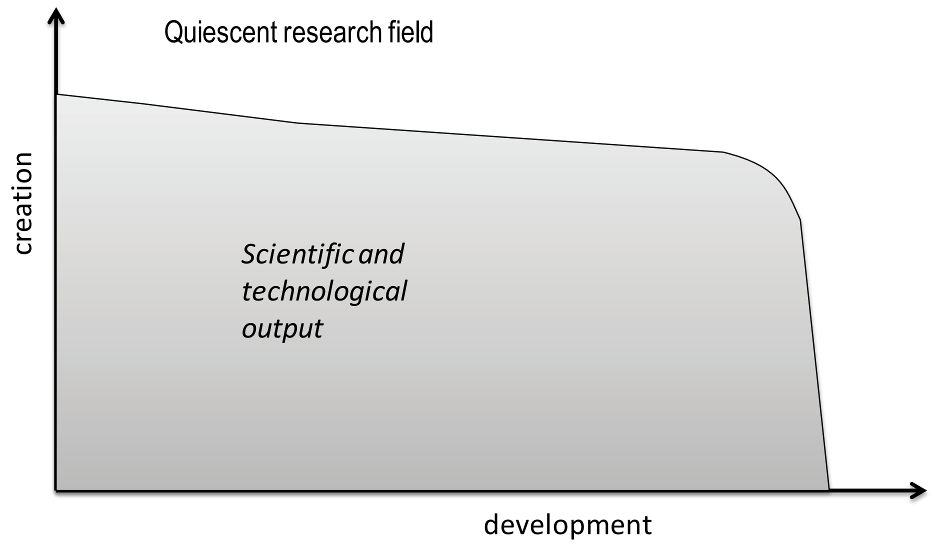

Figure 2. Creation versus development in a quiescent research field

In view of the model outlined above, research teams must periodically appraise their positioning in the research field and the whole scientific system as well. Adaptation at the individual and team levels is required to progress in social recognition, and to keep research teams alive.

5 The challenges ahead

The European Union (EU) is about to launch the new research program HORIZON 2020, for the period 2014-2020. EU programs are important because they usually become referentials for all the European Research Area (ERA). It is recognized that "*Science and innovation are key factors that will help Europe to move towards smart, sustainable, inclusive growth, and along the way to tackle its pressing societal challenges"* [3].

Accordingly, HORIZON 2020 conveys a clear economic purpose: *"The key driver of the problems is Europe's structural innovation gap: compared to its competitors, Europe's patenting performance is weak and it lags behind in developing new products,* *new processes and new services. To boost productivity and growth, it is critically important to generate breakthrough technologies and translate them into new products, processes and services"*[3].

In this way, a marked shift of the current research priorities is expected to occur until the end of this decade that will redirect research preferentially to sectors of strong market value. This goal is expressed clearly by the promoters of this new program, by stating: *"The current separation between research and innovation activities is eliminated. Horizon 2020 sets out three strategic policy objectives: raising and spreading the levels of excellence in the research base; tackling major societal challenges; and maximizing competitiveness impacts of research and innovation. Horizon 2020 is structured around three priorities which link directly to these aims. The selection of actions and instruments is driven by policy objectives and not by instruments"*[3].

In what respects to the CGE main fields of research, only "climate action, resource efficiency and raw materials" deserve some mention (ref. [4], Ch. 5), along with the "Broad lines of the activities": *(a) Fighting and adapting to climate change; (b) Sustainably managing natural resources and ecosystems; (c) Ensuring the sustainable supply of non-energy and non-agricultural raw materials; (d) Enabling the transition towards a green economy through eco-innovation; and (e) Developing comprehensive and sustained global environmental observation and information systems.*

Nevertheless, a small CGE research field might find an opportunity with this program due to the relevance given to the specific area of "Secure, Clean and Efficient Energy" (Ch. 3 in Ref. [4]).

This new policy deserves scrutiny at least from the historical perspective. The prospective new alignment of the EU research policy is going to shift towards the development axis (see figs. 1 and 2) turning out the global scientific system more quiescent. Gains are expected from the side of "innovation", new products, and new practices, and so on. In the short term, positive impacts might be expected in the economy, yet in the long term there is the strong risk of deceleration in the axis of creation, which is the basis for a long-standing and sustainable growth of economies and societies. History shows that the most impressive periods of growth both from the economical and the social side were driven by strong creation intensity (scientific and technological) that opened new frontiers to development. As A. Bejan [2] concluded for the case of the apparent conflict between the individual investigator and the research empires, optimality of the system is always achieved trough balancing contributions of both. We extend that conclusion to the case of the scientific policy by stating that optimality must be achieved through a continuous balancing between creation and technological development.

Thought the Portuguese Scientific and Technologic policy is not yet known in detail, a strong alignment with the European guidelines is expected to occur. FCT has already announced policy goals similar to those of HORIZON 2020, namely, that the selection of actions and instruments will be driven by strategic objectives, quality, and not under the current framework of funding of research units. In this way, the existing research units will be compelled to reshape, redefine objectives, and make networking for pursuing competitive funding. CGE faces such a challenge in the next future.

6 Conclusions

The history of scientific systems in Europe and the United States of America shows similar growth patterns, namely in the fact that both were driven by public and private funding. It was noted that both systems are composed of a constellation of teams and research units, yet in both systems neither the individual investigator has disappeared not most of the research teams have coalesced into huge teams (the research empires), rather one observes a team size distribution that ranges from the individual investigator to the research empire.

We noted that the model of a scientific system put forward by A. Bejan (2008) is able to describe the main features of current scientific systems. One major result that springs from Bejan's model is: "*the apparent conflict between research empires and individuals is not a conflict: it is a balance that serves the institution as a whole*".

Having analyzed the internal dynamics of scientific systems in terms of the creation and development axes we noted that actual systems evolve in time under dominance either of creation or of development (extension), thus defining periods of strong creation that alternate with periods of quasi-quiescence. We also noted that the foundations of the new European program HORIZON 2020 will tend to push the European Research Area towards the development axis, thus rising up the risk of stagnation (quiescence) of the whole system in the long term.

References

1. S. Sörlin, "Trends and issues in the funding of research with some passing reflections on the implications for Higher Education", UNESCO document, code: HED/POL/2007/PI/46, UNESCO, Paris (2007).
2. A. Bejan, "Constructal self-organization of research: empire building versus the individual investigator", *Int. J. of Design & Nature and Ecodynamics,* Vol. 3, No. 3 1–13 (2008).
3. EU Commission, "Horizon 2020 - The Framework Programme for Research and Innovation - Executive Summary of the Impact Assessment Report", COM(2011) 808 final, http://ec.europa.eu/research/horizon2020/ (accessed November, 7, 2012).
4. EU Commission, "Establishing Horizon 2020 - The Framework Programme for Research and Innovation (2014-2020)", 2011/0401 (COD), http://ec.europa.eu/research/horizon2020/ (accessed November, 7, 2012).