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Entrepreneurial experiments in science policy: Analyzing the Human Genome Project

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ABSTRACT

We re-conceptualize the role of science policy makers, envisioning and illustrating their move from being simple investors in scientific projects to entrepreneurs who create the conditions for entrepreneurial experiments and initiate them. We argue that reframing science policy around the notion of conducting entrepreneurial experiments – experiments that increase the diversity of technical, organizational and institutional arrangements in which scientific research is conducted – can provide policy makers with a wider repertoire of effective interventions. To illustrate the power of this approach, we analyze the Human Genome Project (HGP) as a set of successful, entrepreneurial experiments in organizational and institutional innovation. While not designed as such, the HGP was an experiment in funding a science project across a variety of organizational settings, including seven public and one private (Celera) research centers. We assess the major characteristics and differences between these organizational choices, using a mix of qualitative and econometric analyses to examine their impact on scientific progress. The planning and direction of the Human Genome Project show that policy makers can use the levers of entrepreneurial experimentation to transform scientific progress, much as entrepreneurs have transformed economic progress.

1. Introduction

The traditional role of science policy has been to establish and allocate government funding of scientific research. Policy makers within the key funding agencies serve as investors in the scientific community. Rather than simply responding to the supply of scientific projects, they use a variety of programmatic structures and research themes to shape both the level and direction of scientific progress. This role is justified by the long-held notion that public R&D spending should emphasize support of research in areas that are critically underinvested because they are subject to market failures (Bush, 1945; Arrow, 1962). While funding remains key to high levels of scientific output, science policy has recently been subjected to a variety of criticisms: observers have argued that the funding agencies are too conservative in their investment approach, focusing on a limited number of low-risk research projects (Kolata, 2009; Groopman, 2001). Others have pointed to the funding preferences towards older scientists with proven record of productivity thus reducing diversity (Stephan, 2008). Finally, there is limited attention paid to the diversity of the particular organizational and institutional arrangements within which scientific research is undertaken (Murray and Stern, 2007; Jones et al., 2008; Huang, 2009). Together, these criticisms point to the limited diversity of scientific research. This finding underscores the need for science policy makers and scholars to respond to recent economic theory that argues for more significant diversity in early stage research (and researchers) to ensure that the full landscape of scientific paths is explored and that suggests the importance of particular institutional choices in enabling such diversity (Aghion et al., 2008; Acemoglu, 2009; Acemoglu et al., 2009; Murray et al., 2009).

To meet the goal of increasing the diversity of scientific research, researchers and organizational arrangements, we argue that the government should re-conceptualize its role in science policy from investor to entrepreneur. Specifically, we suggest that science policy be reframed so that its core mission is to seed and support entrepreneurial experiments, encouraging the use of diverse technical, individual, organizational and institutional approaches to solve a particular problem. The experimentation perspective on entrepreneurship highlights the power of entrepreneurs to initiate a wide variety of economic experiments in the economy in order to rapidly learn about the effectiveness of different technologies, market needs and organizational arrangements (Rosenberg, 1992; Stern, 2005). While the government may not undertake all

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such experiments directly, within the realm of science policy there is strong potential to act as an entrepreneur by seeding experiments and focusing proactively on assessing their results from this perspective (Greenstein, 2007). Doing so, we argue, would move the government from its more typical role as a reactive investor to an entrepreneur that initiates a wide repertoire of effective interventions into the scientific community. With a proactive agenda of learning from the richly diverse set of entrepreneurial experiments, the government would also be able to promote the broader "science of science and innovation" or "science of science management" agenda. Implementing this broader agenda requires an understanding of the determinants of scientific progress and a more analytic approach to assessing the impact of technical, individual and organizational choices on scientific productivity (Lane, 2009).

In this paper, we illustrate the power of the experimentation approach to shed light on the impact of organizational diversity on scientific progress, using a large-scale entrepreneurial experiment organized by the U.S. government. While recognizing the benefits of science policy experiments ever since the Manhattan project developed the atomic bomb during World War II (Nelson, 1961), the funding orientation of the U.S. government has not been explicitly characterized as government engagement in valuable entrepreneurial experiments that the market alone would not provide nor has it been analyzed as such. In particular, viewing each of the parallel scientific paths sponsored by government agencies (including those under the auspices of the Small Business Innovation Research (SBIR)) as an "experiment" provides a framework for analyzing how a particular scientific challenge can be more or less effectively accomplished using a variety of different technical and organizational choices. This in turn deepens our understanding of the link between organizational arrangements and scientific productivity.

The entrepreneurial experiment we explore in this paper is the Human Genome Project (HGP), (or more precisely the Human Genome *Projects*) funded by the United States Department of Energy (DOE)[2] and the National Institutes of Health (NIH),[3] as well as the Wellcome Trust in the United Kingdom. While typically regarded as one monolithic science project, in fact this massive effort to sequence the entire human genome was carried out in seven public research centers each with different organizational arrangements. Moreover, about eight years after the public Projects' initiation, start-up Celera Genomics began a separate, privately funded quest to complete a full genome sequence, using an alternative technical approach and carried out with an entirely distinctive organizational model: both the organization of the work and the institutions governing data access contrasted sharply with the public Projects.

The remainder of this paper proceeds as follows: In Section 2 we provide a deeper understanding of the nature of entrepreneurial experiments and their application to science policy. In Section 3 we then use this framework to describe the Human Genome Project(s) as an entrepreneurial experiment. In Section 4 we analyze the impact of different organizational choices on the productivity of the different HGP groups illustrating the potential for program evaluation of different experiments. In Section 5 we provide a broader framework for the design and evaluation of economic experiments in the science policy setting.

2. Economic experimentation

We are all familiar with the central role of scientific experimentation in the pursuit of technical progress; it has become a foundational tenet of progress (Merton, 1968) not least because even with the most detailed theoretical models, it is rarely possible to predict *ex ante* the most appropriate research line an advance of an experiment. While scientific or technical experiments are widely understood, economic experiments are harder to envision. An economic experiment can be defined as the choice of a particular combination of technical, market and economic characteristics that form the basis of an opportunity that will hopefully create value and economic gain (Rosenberg, 1992). With our focus on experiments designed to increase the degree of scientific productivity (rather than on economic value per se), we use the term entrepreneurial experiment because as Stern (2005, p. 16) notes, "*While economic experiments can be (and are) implemented in established companies (and can even be found in the public sector), economic experimentation is at the heart of the entrepreneurial process.*" Thus we can consider experiments in science policy as key entrepreneurial experiments.

In the realm of science policymaking and the allocation of government research funding, we argue for the critical importance of entrepreneurial experiments expanding, varying and testing the causal impact of different technical, organizational and institutional arrangements on the creation of scientific value. This follows from the view that experimentation should focus not only on generating information about the best technical path but also determine the best organizational or institutional approach – in much the same way that companies experiment with the most effective market application or business configuration (Greenstein, 2007). The analogy is simple: scientists might use economic experiments to reduce the uncertainty about the way in which particular factors increase or decrease their probability of success. These factors can involve particular combinations of technical approaches, but they can and should also be organizational. Although some argue that science cannot be "managed" and is a black box inside which "unmanageable" individuals ply their craft, evidence suggests that specific interventions in organization, incentives, governance do in fact shape scientific productivity as do broader institutional interventions such as ownership, sharing and exchange (Furman and Stern, 2006; Henderson and Cockburn, 1994; Murray and Stern, 2007; Huang and Murray, 2009; Huang, 2009). If these interventions do in fact shape the outcome of scientific projects, then opportunities for economic experiments abound well beyond the traditional technical domain. The government is well placed to serve as an entrepreneur in seeding and promoting these experiments, thus increasing the diversity of scientific research along many dimensions.

Entrepreneurial experiments are of potentially significant value because, as Rosenberg (1992, p. 181) has persuasively argued, "*The freedom to conduct experiments is essential to any society that has a*

[2] After the atomic bomb was developed and used, the U.S. Congress charged DOE's predecessor agencies (the Atomic Energy Commission and the Energy Research and Development Administration) with studying and analyzing genome structure, replication, damage, and repair and the consequences of genetic mutations, especially those caused by radiation and chemical by-products of energy production. From these studies grew the recognition that the best way to study these effects was to analyze the entire human genome to obtain a reference sequence. Planning began in 1986 for DOE's Human Genome Program and in 1987 for the National Institutes of Health's program. The DOE-NIH U.S. Human Genome Project formally began on October 1, 1990, after the first joint 5-year plan was written and a memorandum of understanding was signed between the two organizations.

[3] The National Institutes of Health (NIH), founded in 1887, is one of the world's premier medical research centers, and the federal focal point for medical research in the U.S. The NIH, comprising 27 separate Institutes and Centers, is one of eight health agencies of the Public Health Service which, in turn, is part of the U.S. Department of Health and Human Services. The primary mission of NIH is to "acquire new knowledge to help prevent, detect, diagnose, and treat disease and disability, from the rarest genetic disorder to the common cold. . .[and] to uncover new knowledge that will lead to better health for everyone." By its key involvement in the HGP, NIH works toward that mission and advances human health by "conducting research in its own laboratories; supporting the research of non-Federal scientists in universities, medical schools, hospitals, and research institutions throughout the country and abroad; helping in the training of research investigators; and fostering communication of medical and health sciences information."