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Fostering breakthrough technologies — How do optimal funding decisions depend on evaluation accuracy?

Eeva Vilkkumaa [a,*], Ahti Salo [a], Juuso Liesiö [b], Afzal Siddiqui [c,d]

[a] Department of Mathematics and Systems Analysis, Aalto University School of Science, P.O. Box 11100, 00076 Aalto, Finland
[b] Department of Information and Service Economy, Aalto University School of Business, P.O. Box 21220, 00076 Aalto, Finland
[c] Department of Statistical Science, University College London, Gower Street, London WC1E 6BT, UK
[d] Department of Computer and Systems Sciences, Stockholm University, DSV, Borgarfjordsgatan 15, SE-164 40 Kista, Sweden

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ABSTRACT

There is a growing interest in fostering breakthrough technologies that offer exceptionally high value to society. However, when starting technology projects, it is impossible to know which of them have the potential to lead to breakthroughs. Therefore, organizations have adopted funding policies in which on-going projects are subjected to interim evaluations based on which some projects may be abandoned to release resources for seizing new opportunities. In this paper, we study which funding policies are optimal when the objective is either (i) to maximize the expected value of the project portfolio, or (ii) to maximize the expected number of exceptionally excellent projects that may lead to breakthrough technologies. We show that the optimal policy for funding exceptionally excellent projects is to start a large number of projects and abandon a high proportion of them later, whereas the optimal policy for maximizing the expected value of the project portfolio is to grant long-term funding to a smaller set of projects based on initial evaluation. Furthermore, we show how the trade-off between these two objectives depends on the initial project evaluation accuracy and the rate at which this accuracy improves. Our results suggest that this trade-off is particularly significant when the initial project evaluations are very uncertain but become more accurate soon after the projects have been launched. In such a setting, policies that seek to maximize the expected portfolio value may fail to promote breakthrough technologies.

1. Introduction

Fostering of breakthrough technologies has in recent years become one of the key objectives of many organizations, such as governmental institutions and public research funding agencies. The policy interest in breakthrough technologies stems from the potential of such technologies for creating extensive industrial development, enhancing national competitiveness, and generating employment and export growth (Sharpe et al., 2013). Moreover, breakthrough technologies may result in the establishment of 'new technology platforms' with applications across a range of products and markets. For instance, Liquid Crystal Displays (LCDs) developed in the 1960s have since grown into a global industry with applications ranging from pocket calculators to televisions and laptops. Also, fiber-optic communication systems developed in the 1970s, together with successive waves of innovation in optical fibers and fiber amplifiers in the 1980s, have accelerated the expansion of the Internet age by allowing huge amounts of data to be transmitted.

Breakthrough technologies such as those mentioned above are extremely rare. Therefore, the objective of promoting breakthrough technologies is typically pursued by trying to identify and fund exceptionally excellent technology-related

* Corresponding author.
E-mail addresses: eeva.vilkkumaa@aalto.fi (E. Vilkkumaa), ahti.salo@aalto.fi (A. Salo), juuso.liesio@aalto.fi (J. Liesiö), afzal.siddiqui@ucl.ac.uk (A. Siddiqui).

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activities which have the potential to result in breakthroughs. Governments, for instance, invest in training highly skilled staff for research laboratories, provide R&D subsidies and grants to private companies and public research institutes, and act as first customers for new technologies through public procurement (Sharpe et al., 2013). Many research funding agencies have dedicated programs for supporting exceptional excellence; the National Institutes of Health (NIH), for instance, have established a high-risk, high-reward research program for 'scientists of exceptional creativity who propose highly innovative approaches to major contemporary challenges in biomedical research' (NIH, 2014). The European Research Council (ERC), too, seeks 'to support the best of the best scientific effort in Europe', expecting that 'its grants will help to bring about new and unpredictable scientific discoveries — the kind that can form the basis of new industries, markets, and broader social innovations of the future' (ERC, 2014).

Decisions about which technology-related activities (henceforth referred to as *projects*) to fund are typically based on evaluation of project proposals. At the time of launching a project, however, it is usually impossible to know whether the project will be exceptionally excellent. Thus, to avoid the prospect of committing resources to projects that will ultimately fail, organizations have adopted flexible funding policies in which on-going projects are subjected to interim evaluations and, based on these evaluations, some projects are abandoned to release resources for seizing fresh opportunities (O'Connor et al., 2008; Tellis et al., 2009; Tian, 2011). The value of such flexibility, called the *abandonment option* in the real options literature (Dixit and Pindyck, 1994), has been studied extensively in contexts where the objective is to maximize the expected value of the project or project portfolio (e.g., Roberts and Weitzman, 1981; Huchzermeier and Loch, 2001; Gustafsson and Salo, 2005; Santiago and Vakili, 2005). Yet, to our knowledge no quantitative models have been developed to support the shaping of policies that promote breakthrough technologies through funding exceptionally excellent projects.

In this paper, we develop a multi-period project portfolio selection model and, specifically, establish guidelines for the optimal funding, evaluation, and abandonment of projects when the objective is either (i) to maximize the expected value offered by the projects or (ii) to maximize the expected number of projects which have exceptionally high values ex post exceeding a given threshold level. We establish these guidelines by solving a two-stage stochastic programming problem in which the discrete decision variables consist of (i) the number of projects that are launched, re-evaluated, and abandoned and (ii) the number of periods for which projects will be funded before they are re-evaluated. We also derive analytic necessary conditions for optimal funding policies, which allow us to solve the optimization problems with a reasonable computational effort.

The results of our model suggest that to maximize the expected value of the project portfolio, one should provide full funding to those technology projects which appear the best based on the initial evaluation. This policy differs from the optimal policy for promoting breakthrough technologies through funding exceptionally excellent projects, which is to launch a large number of projects, re-evaluate most of them after some time and, based on the resulting information, abandon a high proportion of on-going projects. The trade-off between these two objectives is shown to depend largely on the accuracy of the initial project evaluations and the rate at which this accuracy is improved. This trade-off is particularly significant, if the initial project evaluations are very uncertain but become more accurate quickly after the projects have been launched. The important implication of these results is that policies which seek to maximize the expected portfolio value may fall far short of promoting breakthrough technologies, and vice versa.

2. Related literature

Arthur (2009) defines a technology as 'a collection of phenomena captured and put to use'. Breakthrough technologies are defined by Sharpe et al. (2013) as 'novel and discontinuous innovations that result in significant and irreversible changes and are based on new, under- or unexploited physical, chemical, and biological phenomena that allow order of magnitude improvements in the performance of existing products and/or the creation of entirely new ones'. The potential for large improvements compared to existing practices is also captured by related terms that are often used interchangeably in high technology management literature, such as radical innovation (Utterback, 1994) and disruptive technology (Christensen, 1997).

The promotion of breakthrough technologies and radical innovation has so far been examined mostly through empirical studies. O'Connor et al. (2008), for instance, use data from 85 individuals involved with innovation efforts in large firms and conclude that real options approaches and experimental learning have strong positive effects on innovation success. Klingebiel and Rammer (2011) study the innovation performance of 1500 German companies and note better performance among those firms that allocate resources to a broad range of projects and terminate those with unfavorable prospects. Tellis et al. (2009), building on survey and archival data of 750 firms worldwide, conclude that the strongest drivers for radical innovation include the willingness to cannibalize on the firm's current assets to get ahead with the next generation of innovation; the ability to realize the limitations of the current technology and the emergence of a dominant one; and the tolerance for risks associated with trading the current, certain profit stream for a new, uncertain one.

From the perspective of public policy, there is plenty of research on the right 'mix' of policy instruments to support the performance of the innovation system (Borrás and Equist, 2013; Marxt and Brunner, 2013; Sharpe et al., 2013). Due to institutional factors, though, the effectiveness of such instruments – including government incubators, seed funding, and loan guarantees – may vary greatly between different countries (Hall and Lerner, 2009). As a general guideline, Lerner (2009) suggests that the policy instruments should be sufficiently preserving but, on the other hand, their efficacy should be regularly monitored so that inefficient policy instruments could be abandoned or modified to meet the needs of the changing market environment. In the context of research funding, similar conclusions have been made regarding the need for a balance between committing to research projects for a sufficiently long period of time on the one hand, and being able to seize emerging opportunities on the other hand. In particular, short-term funding has been found to encourage risk averse research strategies and to generate proximate and often predictable