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Forecasting Innovation Pathways (FIP) for new and emerging science and technologies

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ABSTRACT

"New" and "Emerging Science" and "Technologies" ("NESTs") have tremendous innovation potential. However this must be weighed against enormous uncertainties caused by many unknowns. The authors of this paper offer a framework to analyze NESTs to help ascertain likely innovation pathways. We have devised a 10-step framework based on extensive Future-oriented Technology Analyses ("FTA") experience, enriched by in-depth case analyses. In the paper, we describe our analytical activities in two case studies. The nanobiosensor experience is contrasted with that of deep brain stimulation in relative quantitative and qualitative emphases. We close the paper by reflecting on this systematic FTA framework for emerging science and technologies, for its intended goal, that is to support decision making.

1. Introduction

In an age of strategic science and high-investment projects decision makers want to identify possible and promising directions and options for technology emergence in advance, to help choose the right path. New and emerging science and technologies, such as proteomics, bioelectronics or nanotechnologies, may impact many sectors with a variety of industrial structures. Regulation and policy instruments therefore need support systems to augment their targets — a variety of (and often shifting) industrial contexts. This emphasizes the requirement of *relevant* and *timely* strategic intelligence to enable effective decision making and strategy development.

For such a support system, FTA tools have to be well tailored to be able to capture the complex world of emerging technology fields, at an early stage, and be robust enough to produce useful intelligence in real-time, often when data are heterogeneous and dispersed.[4] Research and innovation activities for NESTs are embedded in uncertainties, promises, and, sometimes, concerns because:

- The technology is either new or rapidly evolving;
- Applications and markets range from the non-existent to relatively advanced;

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[4] When attempting to capture R&D at early stages of emergence, the analyst is often faced with a subject that has little or no history, few stabilized definitions of what the field actually contains (or doesn't contain), and a difficulty to define community of actors involved either at the core or periphery of the field.

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- Knowledge is emerging in distributed pockets of research and development, often with no easily identifiable community;
- A variety of objectives and visions proliferate; and
- The platform nature of many new technologies means that a variety of routes to diverse applications may be possible.

Thus, FTA for NESTs requires adaptation of traditional technology forecasting methods. Furthermore, the variations within NEST technology management situations demand that FTA methodologies be flexible. For instance, in one case one may have time series data on technical parameters and market development; in other cases, this may not be so.

"Nano" (nanoscience and nanotechnology) includes a range of potential NESTs. In contrast with biotechnology or neuro-cognitive science, nano is not a domain with substantial coherence. It can be defined as being about everything interesting that happens at the molecular level. Nano is an umbrella term (continuing to exist because of the rhetorical and resource-mobilization force of the label), and under this umbrella there are domains with very different dynamics.

Unlike previous high-technology waves, nanotechnology covers diverse fields of sciences and engineering, crosses boundaries between them, and aims to utilize the very fundamental characteristics of matter by manipulation and control at the nanoscale. As they cross many disciplines, also many industrial and technology chains, nanotechnologies are reshaping existing organizational arrangements. Nano R&D requires a large degree of integration, from convergence of research disciplines in new fields of inquiry, to new linkages among R&D labs, multinationals and start-ups, and a panoply of stakeholders.

Nanotechnologies, and other NESTs, have the potential to influence many value chains, create new ones, and will co-evolve with governance processes (markets, regulation, user practices etc.). The field is new; with limited history which complicates trend extrapolation, and there are relatively limited applications in the marketplace. In addition nanotechnologies can be novel themselves, or they can augment existing technologies, and even reinvigorate previously dormant technology developments.

Decision makers interested in developing targeted research and innovation policy, or industrial strategies for that matter, require support in capturing, sorting and distinguishing the actual developments in a particular technology or product application area from the plans and promises (including expectations) in circulation. Forecasting NEST innovation pathways poses a considerable challenge for FTA practitioners.

1.1. A tailored approach

For innovation to succeed in areas like nanotechnology, actor alignment from the research laboratory to product development and eventual application area is necessary. Alignment is easier to achieve where the technology field is well understood; the actors are known, with their relationships already functioning; and where regulation is largely unambiguous. This is the case with incremental innovation in established technological paradigms. For NESTs, such as micro/nanotechnologies where architectural (radical) innovations might occur, conditions of non-linearity and high technology and market uncertainty are typical [1–3].

Despite the high uncertainty, decision makers need to identify possible directions and promising options. Supporting them presents challenges for current strategic technology intelligence and forward-looking assessment tools.

A promising approach to do this, which is sensitive to the complexities of emergence of NESTs, is that of capturing and exploring multiple potential innovation pathways [4,5]. In our approach of Forecasting Innovation Pathways ("FIP"), indicators of developments in the field of technology are ascertained and explored to identify path dependencies. Such pathways may be broad and tentative, but offer opportunities for insights into shared expectations [6], and emerging stabilizations in the technology development processes. These can be brought together to identify endogenous futures — because there are emerging irreversibilities in ongoing socio-technical developments, based on plans and other forms of shared agendas, mutual dependencies and network ties. Pathways from the present to the future are based on the dynamics of the present – this means there are "endogenous futures" [7] embedded in the present which can give indications and insights into the transition from present into future – even if capturing these indications is a formidable challenge.

Such an approach relies on awareness of the rapidly evolving nature of the field and smart ways of capturing a large amount of data sufficient to ascertain the dynamics of emergence. A characteristic feature of NESTs is that data are often located in a variety of pockets, and are often heterogeneous in nature — a consequence of the NEST being at a nascent stage of development. Keeping this in mind, any FTA tailored for a NEST should combine empirical and expert information resources to capture indications of potential innovation pathways if it is to be effective.

2. Towards an FIP framework for NESTs

In order to create a framework for capturing indications of endogenous futures, we distinguish distinct aspects that help us formulate requirements for an FIP analytical system:

(1) How best to capture the NEST's development situation? Many existing FTA approaches focus on exploring future possibilities, neglecting to make sure that we understand key "forces and factors" of the current situation [8–10].
(2) How to build upon the current analyses to address the emergence and evolution of the field? Which dynamics are important? — This has implications for point 1. What sorts of data and analyses are needed [11] for evaluating emerging fields of technology? — This has implications for the following point 3 as well.