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Mapping evolutionary trajectories: Applications to the growth and transformation of medical knowledge

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Abstract

This paper is concerned with the mechanisms through which medical knowledge emerges, grows and transforms itself. It is a large-scale empirical analysis of the development of treatments for coronary artery disease, which is the most common cause of death in developed countries. We uncover the structure of medical understanding of the disease and the path-dependent co-evolution of scientific and technical knowledge in the search for solutions to the relevant set of problems. After reviewing a broad range of secondary sources and a number of interviews with leading clinicians, we use new tools recently developed for the longitudinal analysis of large citation networks. We apply them to a bibliographic database of 11,240 papers published in the area of coronary artery disease between 1979 and 2003 and to a patent dataset of 5136 US patents documents granted between 1976 and 2003 for angioplasty-related devices. The results are consistent maps, which we critically discuss, of the major scientific and technological trajectories associated with one of the most important medical procedures of the last 30 years.

Keywords: Medical innovation; Technological trajectory; Problem sequence; Longitudinal network analysis

1. Introduction and scope

While more needs to be done to extend the proportion of the world population that benefits from advances in medical sciences and technologies, it is difficult to disagree that these stand among the proudest achievements of the last century. Medical innovation has been and continues to be a source of hope for prevention, effective treatment, and cure of disease; it constitutes one of the obvious areas where progress is made in a non-trivial way to extend the gift of life or improve its quality.

This paper is concerned with the mechanisms through which medical knowledge emerges, grows and transforms itself. This is a process that is distributed across time, space and epistemic domains. It involves the development of correlated understandings about the nature of medical problems and the search for solutions to these problems. It entails a shift from the exploratory undertaking of inquisitive individuals to the more systemic interactions of dispersed groups of practitioners competing and cooperating to solve scientific and technical puzzles in a variety of institutional settings and different incentive structures. How does this happen and how does it lead to improvements in the treatment of diseases? What does the innovation literature have to say on this matter?

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In a recent contribution on the evolution of human know-how,[1] Nelson (2003) stresses the unevenness with which advance is achieved across different classes of human needs, and these include health needs, many of which have been successfully met and many have insofar eluded satisfactory solutions. With reference to medicine, Nelson emphasises the fundamental role of *practice*, intended as the actual application of human skills to a task, beside the role of articulated blueprint knowledge.[2] He highlights the importance of co-ordinating know-how embodied in different individuals and groups and argues that 'cumulative advance of know-how must be understood as a process of "cultural learning" or evolution' which '. . . in turn, involves the co-evolution of technique and understanding' (p. 1).

On similar lines of thought, Mokyr (1998) discusses the problem of medical knowledge in relation to principles of evolutionary epistemology. He emphasises the key role of scientific and technological capabilities as the necessary pre-condition for induced technical change in medicine and identifies the 'technique' as the main unit of selection. This is defined as '. . . a set of instructions, if-then statements (often nested) that describe how to manipulate nature for our benefit, that is to say, production widely defined' (p. 122). The underlying structure of the system is the set of *useful knowledge* that exists in a society, including untested beliefs and prejudices, which relates to the manifested entity of a set of *feasible techniques* that are tested and evaluated in order to define what technique – or medical routine – will be put to actual use among those available at any moment in time.[3]

Gelijns and Rosenberg (1994) also provide a number of fundamental insights into the dynamics of technological change in medicine upon which we rely for this study. They stress the inadequacy of linear models to account for the salient characteristics of medical innovations. First of all, linear models neglect feedback mechanisms between phases of adoption and use and applied research and development, so as to cancel out the fundamental uncertainty associated with the introduction of innovations into clinical practice and the prolonged need to adapt the technology while drawbacks (i.e. side-effects of drugs) and potential improvements, leading over time to significant incremental change, become apparent through actual use.

Secondly, only 'open', models allow to capture the fact that innovations may come not from biomedical research in the first place, but from other fields.[4] The development of medical devices is especially dependent on a number of technological competences that are not core to health sciences (i.e. optical engineering) and cannot be understood if not in association with the surgical practice in which they are utilised. A third aspect of medical innovation that is not easily accommodated by a liner understanding of its development is the role – and dynamics – of demand. A variety of factors on the adopters end of the spectrum are crucial to the creation of markets for new technologies. Hospital administrators, insurers, patients and regulators are increasingly influencing the rate and direction of medical innovation by explicitly identifying priority needs and re-defining modes of financing that incentivise the emergence and diffusion of cost-reducing technological solutions.[5]

Gelijns et al. (1998) further elaborate on the characteristic uncertainty of medical innovations and the importance of improvements through practice. They argue that 'innovation is a learning process that takes place over time, and a fundamental aspect of learning is the reduction of uncertainty' (p. 694). However – they argue – not all uncertainties can be eliminated in the process and this is valid for both positive and negative unexpected consequences of the application of new treatments. Uncertainty results from the complexity of the human system, which poses severe limits to the possibility of predicting the effects of new procedures.[6] The

[1] Know-how is there defined as 'the wide range of techniques and understandings human societies have acquired over the years that enable them to meet their wants' (2003: 1).

[2] The debate on the tacit versus codified nature of different kinds of knowledge has been explored by a great deal of contributions to the innovation literature. Although awareness of the debate informs parts of our study, this does not constitute its main focus.

[3] Mokyr's discussion of the mapping function connecting knowledge and techniques is extremely interesting and leads to a number of considerations that are very close to the present study, among which the role of rules of falsification, the mechanisms of survival, obsolescence and resistance to change, as well as the problem of the accessibility of knowledge. Space constraints and the empirical nature of this paper do not allow a thorough discussion of so rich a contribution, but traces of its insights can be found between the lines of this study.

[4] This is the rather well known case of ultrasound, laser and magnetic resonance technologies, among the many possible examples.

[5] This is not meant as an endorsement of a 'demand-pull' perspective. Innovation 'on-demand', however desirable in medicine of all fields, does not reflect the long-term struggle of mankind with diseases, many of which cannot yet be solved even if the need for solutions could not be stronger. For a critique of demand-pull models in medicine, see Mokyr (1998).

[6] Metcalfe et al. (2005) note that like all medical innovations, application to the human body is more a matter of engineering than of science. Consequently, as with all engineering innovations, feedback from practical application is of the essence of the development of reliable knowledge (Vincenti, 1990).