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# An emerging paradigm or just another trajectory? Understanding the nature of technological changes using engineering heuristics in the telecommunications switching industry

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ABSTRACT

The theoretical literature on technological changes distinguishes between paradigmatic changes and changes in trajectories. Recently several scholars have performed empirical studies on the way technological trajectories evolve in specific industries, often by predominantly looking at the artifacts. Much less – if any – empirical work has been done on paradigmatic changes, even though these have a much more profound impact on today's industry. It follows from the theory that such studies would need to focus more on the knowledge level than on the artifact level, raising questions on how to operationalize such phenomena. This study aims to fill this gap by applying network-based methodologies to knowledge networks, represented here by patents and patent citations. The rich technological history of telecommunications switches shows how engineers in the post-war period were confronted with huge challenges to meet drastically changing demands. This historical background is a starting point for an in-depth analysis of patents, in search of information about technological direction, technical bottlenecks, and engineering heuristics. We aim to identify when such changes took place over the seven different generations of technological advances this industry has seen. In this way we can easily recognize genuine paradigmatic changes compared to more regular changes in trajectory.



## 1. Introduction

Concepts such as technological paradigms and trajectories are extensively used in the literature; however, from an empirical perspective, their use is still rather subjective. In fact, the challenge of their validation concerns both their empirical operationalization and the availability of comparable data. Recent literature on innovation addresses these challenges by defining technological trajectories in terms of knowledge flows within a patent citation network (Mina et al., 2007; Verspagen, 2007; Fontana et al., 2009; Barberá et al., 2010). In such settings, patents are the nodes of the network and citations indicate the knowledge flows between them (Jaffe and Trajtenberg, 2005).

Such data are not only easily available, but also rather suitable for the investigation of technology dynamics as they also disclose qualitative information about the invention. The methodology applied is strengthened and validated in this paper by examining the evolution of the engineering heuristics specific to a technological paradigm. Therefore the novelty of this work is twofold: firstly, to identify and study the evolution of engineering heuristics applied in the telecommunication switching industry, and secondly, as the engineering heuristics pertain to the knowledge level, to explicitly unfold the link between the artifact and knowledge level.

Patents are particularly suitable for these tasks as they must include the background and a description of the invention. In fact, in order to be granted a patent, applications must contain an explanation of an inventions novelty, utility, inventive steps, non-obviousness, industrial applicability, and *prior art*.[1] Thus all this information can be used to understand the type of technical problems tackled by engineers over time, the solution proposed, and therefore the research heuristics applied.

Differently from previous work using the same methodology, this paper emphasises how the quantitative and qualitative analyses complement each other. This link between quantitative and qualitative results is provided by validating the technological trajectory. Firstly, the main flow of knowledge within the patent citation network is identified, and then the patents belonging to this trajectory are scrutinized to find information about the engineering heuristics applied. Discontinuity in heuristics enables us to detect paradigmatic shifts. Therefore, this methodology can be

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[1] See: http://www.wipo.int/patentscope/en/patents_faq.html#protection retrieved on 12 December 2011.

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considered as a meaningful combination of quantitative and qualitative research, enabling in-depth analysis (often lacking in quantitative approaches) and generalization (often missing in narratives).

Furthermore, according to the literature, paradigms and trajectories are features of both the artifact and the knowledge space. Whether those are isomorphic is an empirical question which this paper attempts to answer for the case of telecommunication switches. In this respect, it is commonly accepted that switches have evolved as a sequence of generations of artifacts. This sequence needs to be reappraised within the technological paradigms and trajectories theory. In particular, for each generation some characteristics specific to technology are examined. These are: (i) the competencies needed, (ii) the engineering heuristics applied, and (iii) the perceived technical barriers. All these characteristics (and in particular, the engineering heuristics) relate to the "engineering knowledge" underlying each artifact's design (Mokyr, 2002). Therefore, the joint analysis of telecommunication switches generations and heuristics will allow us to link the artifact level of analysis to the knowledge level, and to associate artifact dynamics with the evolution in technology.

The telecommunication switching industry provides an interesting case for this type of analysis because in the period under examination, its technological evolution is characterized by 'normal' and 'revolutionary' periods. Therefore we are able to appreciate the methodology proposed in the trajectories as well as the paradigmatic shifts. Finally, it is an industry where different generations of switching technologies are easily distinguished.

The results shed some light on the microdynamics of technical change in the industry studied. They show that heuristics can coexist at artifact level, therefore, despite changes at technical and service level, a truly paradigmatic shift can only be detected at knowledge level. Finally, the empirically mapped trajectories correspond with what is commonly accepted. The engineering heuristics identified in the patents as part of the technological trajectories change over time. Consequently, technical change has evolved in different dimensions and a new technological paradigm emerged in the mid 1990s.

This paper is structured as follow: the next section starts by reviewing the empirical literature on technology dynamics, Section 3 will reappraise the known history of telecommunication switches in the framework of technological paradigms and trajectories, Section 4 will discuss in detail the methodology, and finally Section 5 will present the empirical analysis, followed by conclusions.

## 2. Theoretical background

As observed by Dosi and Nelson (2009, p. 5), technology entails "... particular pieces of *knowledge*, *procedures* and *artifacts* ...". Mokyr (2002) relates these pieces by partitioning useful knowledge into *propositional* knowledge and *prescriptive* knowledge, where the first set ($\Omega$) includes knowledge "how" and the second set ($\lambda$) knowledge "what". Following the definition, $\Omega$ "... includes a great deal more [than 'scientific' knowledge]: practical informal knowledge about nature such as the properties of materials, heat, motion, [...] It also include what [...] Walter Vincenti (1990) has termed 'engineering knowledge' (Mokyr, 2002, p. 5) ...". As $\Omega$ provides the cognitive support to all the known techniques in $\lambda$, these sets are related and to a certain extent[2] $\Omega$ maps into $\lambda$. These types of knowledge are differently "stored" and "... unlike $\Omega$-knowledge, a great deal of the $\lambda$-knowledge is stored in the artifacts themselves ..." (Mokyr, 2002, p. 11).

Therefore, the different pieces previously mentioned pertain to two different level of analysis, one related to "engineering knowledge" and procedures and the second one related to the artifacts and their characteristics. Engineering heuristics as part of "engineering knowledge" relate to the former. Despite the fact that these two levels have similar characteristics (and properties) and are necessarily related, the scant empirical literature on technology dynamics tends to focus on the artifact level. However, concepts such as technological paradigms and trajectories belong to both the knowledge and artifact space.

Following the seminal paper by Saviotti and Metcalfe (1984), some studies infer technical trade-offs from technological and service characteristics (i.e. performance indicators). This was done for some complex artifacts as: tanks (Castaldi et al., 2009), helicopters, and aircraft (Frenken et al., 1999). In the same conceptual line and again at artifact level, the N–K model has been used to map the relationship between technical and service characteristics. This biological model lets you relate *N* technical characteristics to a number of functions through *K* relations. And so these two parameters inform you about the complexity of an artifact, the search path in the technological space, and the emergence of certain designs.[3] However, given the definition of technological paradigms and trajectories put forward by Dosi (1982), the artifact level of analysis provides only a partial view of technology dynamics.

In fact, if technical advance is a 'problem solving activity' carried out by engineers, the technological paradigm is defined "... as 'model' and a 'pattern' of solution of selected technological problems, based on selected principles derived from natural sciences and on selected material technologies ..." (Dosi, 1982, p. 152). Following the parallel with the idea of scientific paradigm developed by Kuhn (1962), the technological paradigm binds the extent of exploration by engineers in the technological space. These boundaries can be cognitive, related to the engineering background, or technical, related to the flexibility of production techniques, the artifact design, and technical bottlenecks. Certainly they pertain to the 'challenge-and-response' pattern followed by engineers (Rosenberg, 1974).

Within the set of available solutions defined within the paradigm, the technological trajectory maps the microdynamics of technical change in a 'normal' technological evolution.

In this perspective, it is clear why the study of technology dynamics at the artifact level only partially captures the breadth of the theory of technological paradigms and trajectories. A recent stream of literature proposes a different approach by using patent and citation data for mapping technological trajectories at the knowledge level. These data sources are particularly useful because the description of the invention reveals information about the technical problems tackled and the engineering heuristics applied.

According to the theory, a paradigm is composed by heuristics that are the "search strategy", guiding engineers in their problem-solving activities.[4] These heuristics are the way through which the

[2] The characteristics of these sets, the way, and the extent they are associated is relevant for technology dynamics. For further details see chapter 1 in Mokyr's book *The gifts of Athena. Historical origins of the knowledge economy* (2002).

[3] For more details about the general N–K model, see Kauffman (1993). For applications of this model in technology evolution see Frenken (2000) and Frenken and Nuvolari (2004) for steam engines.

[4] Vincenti (1994) explains the blind variation connected to the innovative process with an interesting metaphor. In his words:

> I think the seeker for knowledge as rather a blind person trying to reach a desired destination by going down an unfamiliar passageway, using tactile input from a cane and the constraint available from the passage's sidewall. (Vincenti, 1994, p. 21)

The cane and the sidewall are the engineering heuristics which guide the search, and make the process not random but just blind.