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# Technology fusion: Identification and analysis of the drivers of technology convergence using patent data

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ABSTRACT

The concepts of technology convergence or technology fusion describe the phenomenon of technology overlap. Despite evidence of the higher value associated to interdisciplinary research and cross-industry innovation, few studies have investigated the characteristics of technology fusion based on patent data. This study identifies new cases of convergence relying on the International Patent Classification (IPC) of patents filed at the European Patent Office between 1991 and 2007: the first occurrence of a patent incorporating a combination of IPC subclasses signals a new instance of fusion. Duration models are employed to investigate the impact of field level characteristics derived from patent bibliometrics on the likelihood of identifying a new fusion. The results show that merges are more frequent if the focal technology fields are closely related (based on a higher number of cross citations), are characterized by wide technological scope, and are the result of an inter-firm collaboration. In contrast to previous findings, the results show that the more complex the technologies involved, the less the likelihood of their convergence or fusion. The correlation between fusion likelihood and the characteristics of the merging fields could help managers and policymakers to predict the emergence of new technology areas.



## 1. Introduction

Technology convergence, fusion, merging, cross-fertilization, and hybridization are all terms used to address the phenomenon of technology overlap which Curran (2013) defines as the blurring of the boundaries between disjoint areas of science, technology, markets, or industries. The topic of technology fusion began to attract attention following Kodama's (1992) seminal piece, and evidence of the higher value associated with interdisciplinary research and cross-industry innovation. At the invention level, converging fields appear to be characterized by greater novelty and more breakthrough results (Schumpeter, 1939; Fleming, 2001; Hacklin, 2007; No and Park, 2010; Nemet and Johnson, 2012; Karvonen and Kässi, 2013); at the firm and sector levels, previous studies on merged fields observe better performance and a relevant impact on industry evolution since technology fusion sustains and revamps innovation trends and generates new trajectories (No and Park, 2010; Kim and Kim, 2012; Curran, 2013; Hacklin et al., 2013). Industry is evolving driven by the faster growth of the merging fields, and the disruptive elements of the products based on the converged technologies (Carnabuci, 2012; Kim et al., 2014).

Technology convergence began to attract attention in the 1980s and even more in the 1990s when diffusion and overlaps among robotics, computing, and information and telecommunication technologies began to have a significant impact on the products and strategies of firms in several industries from information and communication technology (ICT) to consumer electronics, to mechatronics (Kodama, 1992; Lind, 2004). Since then, several fields have been characterized by fusion dynamics (Pennings and Puranam, 2001; Curran, 2013). Telecommunications, ICT, and electronics spread to and merged with several other sectors (e.g., optoelectronics; innovations in packaging; printable electronics; RFID - radio frequency identification - tags; smart-phone, smart-television and smart-home). Chemicals combined with informatics, textiles and materials and these innovations have been competing with agricultural products. The pharmaceuticals industry collaborations have resulted in the emergence of biotechnology, bioinstrumentation and nanotechnology, nutraceuticals and functional foods, cosmeceuticals, and in services (e.g. health care management, insurance and banking) and the so-called "TIME" industry, based on overlaps among telecoms, information technology, media and entertainment (Lind, 2004; Hacklin et al., 2013). In some cases, a specific product has supported the development of other fields (Nemet and Johnson, 2012) such as steam engines, semiconductors, lasers and synthetic fibers.

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Merged fields are usually characterized by opportunities for firm growth based on successful capture and management of the available novel technologies, and competition with incumbents from new sectors (Kim and Kim, 2012). Companies that lack competences in these new fields may be forced to rely on external partners in cross-industry alliances or via a merger and acquisition (M&A) process (Lind, 2004). Definition of the corresponding firm strategies benefits significantly from an increased understanding of the role of technology innovation and the dynamics of the convergence process, especially in the case of disruptive trajectories (Bonnet and Yip, 2009).

Analysis of emerging overlapping trends in patent data, scientific publications, and firm classifications such as the Standard Industrial Classification (SIC) codes could help managers to identify and exploit new opportunities, avoid threats, plan future research and development (R&D) activity, and forecast technological trends in the transformation of industries (Choi et al., 2007; Kim and Kim, 2012; Hacklin et al., 2013; Karvonen and Kässi, 2013). From this perspective, the role of technological forecasting involving interdependencies across technologies, although a complex process can help firms to anticipate change and predict future needs (Jeong and Kim, 1997; Choi et al., 2007; Karvonen and Kässi, 2013). In particular, the study of technological interrelations can provide useful insights into the emergence of new technologies based on combinations of previous stand-alone technologies. More broadly, understanding technology fusion dynamics could be informative for the definition of science and technology policies, by enabling comparison among investments and other forms of support for interdisciplinary areas, with support for existing domains (Nemet and Johnson, 2012).

Several authors have proposed theoretical analyses, taxonomies and case studies of technological convergence (Gambardella and Torrisi, 1998; Nemet and Johnson, 2012; Curran, 2013; Hacklin et al., 2013). Although some propose theoretical methodologies (Pennings and Puranam, 2001; Kim and Kim, 2012) and explore specific technological fields based on data analysis (Choi et al., 2007; No and Park, 2010; Ko et al., 2014), there is no systematic empirical evidence on the overall characteristics of technology convergence. This article aims to fill this gap in two connected ways. First, it proposes a methodological approach to identifying the emergence of a fused technology based on the first combination of two International Patent Classification (IPC) codes, and applies this approach to a large data set of patents filed at the European Patent Office (EPO). Second, it investigates a set of patent-based characteristics, including the level of the linkages among technologies (the "converging process" in Curran, 2013), the technology cycle, and the complexity and value of the merging fields in order to understand their impact on the likelihood of a new fusion.

The article is organized as follows. Section 2 reviews the technology fusion literature and describes how patent data can be used to support empirical analysis and description of technological characteristics which have been theorized as relevant to the overlap processes. Section 3 describes data collection and methodology. Section 4 presents summary statistics and the results of the regression analyses and Section 5 discusses the results and provides some conclusions.

## 2. Research background

### 2.1. Previous literature on technology fusion

Two main research streams are distinguishable in the literature on technology fusion: work focusing on the theoretical aspects, and empirical case study exploration of specific fields and firm- and industry-level data analysis.

A number of studies in the first stream focus on the theoretical definition of convergence (e.g., Kodama, 1992; Hacklin, 2007). In particular, Curran (2013) organizes work on convergence starting from the definition and the usage of associated terms. He defines convergence (or fusion) as: "a blurring of boundaries between at least two hitherto disjoint areas of science, technology, markets or industries; [it creates] a new (sub-)segment […] as a merger of (parts of) the old segments" (Curran, 2013, p. 22).

Curran (2013) notes also the terms "convergence" and "fusion" have slightly different meanings. The former refers to a process in which two elements move towards a new common place; the latter implies that the two elements merge "in the very same place of at least one of the objects". Similar to Curran, this study uses these two terms interchangeably but highlights their difference if relevant to the analysis.

Among prior theoretical studies, the work of Pennings and Puranam (2001) is important because it paved the way to further research on the development of strategic and policy implications related to convergence. Pennings and Puranam's analytical framework distinguishes between demand side and supply side convergence. The latter is related to technological functionality, the former is associated with the contemporary satisfaction of different needs based on different technological capabilities which converged to become similar. Several authors have built on their seminal study. Bröring (2005) identifies additional categories such as "technology-driven input-side convergence" evolving from new technologies applied across different industries, and "market-driven output-side convergence" which occurs when customers start to consider products from different industries in a similar way (e.g., nutrients, dietary supplements, and herbal products included in the category of common food products). In the framework of evolutionary economics, Hacklin (2007) splits the process of convergence into four stages: knowledge, technology, application, and industry convergence. Curran (2013) notes the non-linearity of the process and suggests to consider the four stages as *loci* of convergence: science, technology, markets, and industries. This research is centered on the "technology" *locus* which corresponds to the supply side in Pennings and Puranam's (2001) framework and is motivated by the lack of work on technology convergence highlighted by Kim and Kim (2012).

Furthermore, the paucity of data on convergence between two technologies and the lack of an agreed indicator of interdisciplinarity limit the analysis of technology fusion (No and Park, 2010; Kim and Kim, 2012). Some empirical analyses of convergence employ concept frameworks, case studies or company-level data, in specific technological fields, to provide insights into corporate diversification. Hence, a broader wider approach to provide complementary evidence and extend work at the technology level is needed. The main contribution of the present study is twofold: to propose a method to identify technology convergence at system level relying on patent data and then to analyze the drivers of technology fusions.

### 2.2. Identification of technology fusion through patent data

Analysis of the convergence process among distinct technological fields requires a hierarchical structure to define domains (Murmann and Frenken, 2008; Roepke and Moehrle, 2013). A technological hierarchy enables measurement of technological distance and convergence. Coherently with the unit of analysis (industry, firm, technology), the investigation should rely on widely-accepted classifications such as SIC codes or International Patent Classification (IPC) codes, or on ad-hoc structures of specific keywords. The diffusion of Natural Language Processing tools has supported the analysis of convergence mechanisms in very specific technical fields delimited by sets of keywords (e.g. Roepke and