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Technology clustering based on evolutionary patterns: The case of information and communications technologies ☆

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ABSTRACT

Technology trend analysis anticipates the direction and rate of technology changes, and thus supports strategic decision-making for innovation. As technological convergence and diversification are regarded as emerging trends, it is important to compare the growth patterns of various technologies in a particular industry to help understand the industry characteristics and analyse the technology innovation process. However, despite the potential value of this approach, conventional approaches have focused on individual technologies and paid little attention to synthesising and comparing multiple technologies. We therefore propose a new approach for clustering technologies based on their growth patterns. After technologies with similar patterns are identified, the underlying factors that lead to the patterns can be analysed. For that purpose, we analysed patent data using a Hidden Markov model, followed by clustering analysis, and tested the validity of the proposed approach by applying it to the ICT industry. Our approach provides insights into the basic nature of technologies in an industry, and facilitates the analysis and forecasting of their evolution.

1. Introduction

Technology forecasting anticipates the direction and rate of technology change, so helping inform managers' decision-making processes for such issues as setting the priorities setting, allocating the resources, and reducing the risks inherent in developing technology, at both national and private levels [1]. Governments need technology forecasting to advance public agendas in the face of both increasing rates of technology change and budgetary constraints [2], while companies, facing intensive business sector competition, employ it to prioritise their R&D projects and inform their strategic alliance thinking [3].

Among the various factors that can affect an industry's future, technology development is becoming increasing important [4]. Amidst the ever-faster pace of technological innovation, the processes of technology development have undergone several changes [5], at the centre of which is the merging and overlapping of technologies [6,7], which have meant that as well as diversification, technological convergence or fusion have come to play increasingly important roles in technology development in almost every industry over the past decade [8,9]. The increased interest in cross-disciplinary technologies has resulted in the promotion of collaboration between different scientific and technological fields in the anticipation that such activities would generate breakthroughs at higher rates [10]. This focus has intensified efforts to analyse similarities, differences, and/or relationships between technologies, to increase understanding about an industry and its associated technologies, and so ultimately drive strategic technology development and efficient R&D investment.

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Several researchers have investigated the technology innovation process in industry settings, especially in high-tech industries, viewing an industry as a collection of its relevant technologies, and many have used patent analysis to provide useful data [11]. As a rich source of technical and commercial knowledge about advances in technology and innovative activities, a patent is widely seen as a good proxy measure of technology [12,13]. Its publicly availability means patent data is easily accessible for various analyses, such as longitudinal research [14], so patent analysis has a long history of application — in almost every field of technology — and numerous studies have focused on developing intelligent analysis methods [15–17].

The goal of patent analysis is, in essence, to identify the characteristics of technologies or industries. Citation analysis, one of the most mainstream techniques, measures knowledge flows between technologies and sometimes between clusters of similar technologies [18–21], while other popular approaches include the cross-impact analysis of technologies [22,23], competition analysis of their co-evolutionary processes [4], and how they can be effectively visualised to discover emerging technologies [24]. Patent information has also been used to measure the progress of technologies and to project future technological trends [25–29]. The characteristics of an industry are greatly affected by the technologies it utilises (albeit to varying degrees in different industries), so it is meaningful to investigate the growth patterns of various technologies in a particular industry to help gain insights into that industry's future and to facilitate analysis of its technology innovation processes. However, few previous patent analyses studies have tried to incorporate the growth patterns of technologies, despite the potential value of this approach. And as the focus of most existing trend analysis studies has been on individual technologies, little attention has yet been paid to synthesising and simultaneously comparing multiple technologies. Analysing the growth patterns of multiple technologies could help elucidate what industries core technologies are, so promoting further examination of their possible inter-relationships (e.g. substitutive or complementary).

This research attempts to cluster technologies according to their growth patterns, based on the assumption that the trend of patent applications in a particular field reflects the trend of technological growth in that field. First, a Hidden Markov model (HMMs have been widely used to infer sequential structures of data) is used to model technology growth patterns based on patent data [30], and technologies with similar growth patterns identified by cluster analysis from the HMM results. Using HMMs for trend analysis has several advantages: the technique models raw data to capture true dynamic behaviour, is less sensitive to noise than other techniques, and also shows representative growth patterns of technologies clustered in a group. Finally, we used our approach to investigate technological growth trends in the Information and Communications Technology (ICT) industry, and our results confirmed the suitability of the proposed approach for technology trend analysis. Once technologies with similar growth patterns are clustered, it is possible to identify technologies that are in the same positions in their life cycles, allowing their effects and their future trajectories to be better predicted. Clustering can also be used as a tool to analyse inter-technology relationships by identifying those with similar growth patterns and distinguishing emerging from declining technologies.

This paper is organised as follows: HMMs are briefly explained in Section 2; Section 3 describes our overall research process, the application of an HMM to patent data the interpretation of our results, after which Section 4 presents our case study of the ICT industry and briefly discuss the contributions and policy implications of this research. Finally, we draw conclusions in Section 5.

2. Background

2.1. Theoretical background: taxonomy of technologies

In general, two kinds of approaches can be used to group technologies — classification or clustering. In a *classification* approach, a set of criteria to compare technologies is created, and technologies are then classified based on this set, thus creating a taxonomy of technologies [30,31]. Another popular method is to develop a technology portfolio or indicators for classifying various technologies into several groups (typically four groups when two criteria are used to create a 2 by 2 matrix) [32–34]. The key to this method is to design criteria that both describe technology characteristics well, and are suitable for classification purposes. The classification approach is usually used for strategic purposes based on experts' judgement and thus differs from the approach used in this study, which is based on data analysis. In a *clustering* approach, data that describe technological characteristics are used to cluster technologies with similar characteristics. A popular data source is a patent database, given the extensive technological knowledge included in patent documents, which makes this data useful for examining how technologies behave over time, for identifying technology breakthroughs, and for analysing cross-fertilisation between technologies.

There are two main techniques that can be applied to classify technologies in the clustering approach. The first (which is one of the most frequently used techniques in innovation studies) is based on the *technological knowledge-flows* between different technologies, and usually uses patent citation and network analyses. Citation analysis measures the degree of knowledge flows, allowing the relationships between technologies to be analysed, after which these relationships are visualised by network analysis, which also identifies technologies of particular importance (e.g. in terms of knowledge providers, absorbers or intermediaries). Technologies are assigned to the same group if active knowledge flows are observed between them [35] or where they play similar roles in knowledge flows [35–38]. While this technique is quite useful — because it analyses the direct relationships between technologies — it has the limitation that its analyses are mostly static, so the results provide little insight into the dynamics of technological changes.

The second technique is based on *growth curves* [39,40]. Time-series data for each technology in a database are plotted, and the growth curve model that represents the data characteristics selected, after which the data are fitted to the growth curve to obtain parameter values. This process is then repeated for all technologies, and the parameter values used to group technologies with