A Collective Reasoning on the Automotive Industry: A Patent Co-citation Analysis

Manuel Castriotta and Maria Chiara Di Guardo

{manuel.castriotta, diguardo}@unica.it,
University of Cagliari (Italy)

Abstract
While collective cognition has received increasing attention in the broader field of organization, academic research has largely overlooked its potential role on shaping innovation trajectories and technological change adaptation at a firm and industrial levels. Through a strategic lens and based on the patent bibliometrics and patent co-citation methods, we integrate and extend the cognition and technology strategy literatures by proposing an invention behavior map of leading companies and groups in the automotive industry. How collective cognition influence patent strategies? How economic trends impact on patent paths? Empirical evidence for these reasons is drawn from a longitudinal patent analysis quantitative approach of the period 1991-2013 considered overall and consequently subdivided into three sub periods of seven years each 1991-1997, 1998-2004, 2005-2013. About 443.000 patents, 1.108.356 citations and 1.234.623 co-citations of 49 automotive assignees were collected from Derwent Innovation Index (DII), the largest world patent and innovation database. Multi dimensional scaling and cluster analysis techniques are employed to detect embryonic cognition homogeneity measures and provide an overview of groups technology composition and companies innovation strategies trends. Finally, explorative findings are discussed below with suggestions about how they might be translated into managerial implications.

Conference Topic
Patent Analysis

Introduction
The empirical literature on technological regimes argues that firms within an industry behave in correlated ways because they share sources of information and technology (suppliers, universities, other industries), and perceive similar opportunities for innovation. The existence of a collective cognition shared by firms within a sector can also influence how inventions arise and how quickly and completely they diffuse, and can give us another key to better understand the collective failure of some industries as a result of surprisingly unexpected technological changes, or the innovation trajectories that have characterized some sectors. Yet, while collective cognition has received increasing attention in the broader field of organizational theory (Johnson & Hoopes, 2003; Nadkarni & Narayanan, 2007), research on innovation and patent strategies has been largely silent about the cognition's role (Kaplan, 2011, 2012; Kaplan & Tripsas, 2003, 2008) and empirical studies thus far have not questioned how industry boundaries truly define patent strategies and how economic trends impact on technological trajectories.

To take the first steps at going beyond these limitations and embryonically understand how industry structure and interaction among players can shape technological trajectories, we examine the case of the automotive sector from 1991 to 2013 and identify the dynamic evolution of patent paths among the principal actors in this sector. We chose the automotive sector for several reasons: first, the ability of firms to innovate is crucial to commanding a competitive advantage in this industry (Norhia & Garcia-Pont, 1991); second, all relevant players in this industry must routinely patent their innovations; and third, the automotive market is characterized by high entry barriers able to isolate new entrants and incumbents' dynamic noise.

In order to understand the phenomenon at stake, we analyze the evolution of the technological trajectory in the automotive sector by utilizing bibliometric information such as patent co-citations (Lai & Wu, 2005; Wang, Zhang & Xu, 2011). This approach displays a larger picture of the overall innovation structure and the patent linkages among players and groups' technology positioning, thereby shedding light on the patterns of patent strategies within an industry.

In total, a 21-year period, subdivided as three sets of years in seven-year time spans from 1991 to 1997, 1998 to 2004, and 2005 to 2013, are visualized. About 443.000 patents, 1.108.356 citations and 1.234.623 co-citations of 49 automotive assignees were collected from Derwent Innovation Index (DII), the largest world patent and innovation database. Multidimensional scaling and cluster analysis techniques are employed to detect the embryonic cognition homogeneity measures and to provide an overview of the groups' technology composition and companies' innovation strategy trends.

This study adds to the literature in multiple ways. First, it contributes to the patent literature showing the evolutionary patterns of patent strategies inside a specific industry using patent co-citation analysis. Second, it contributes to innovation literature by enhancing our understanding of how technological firms and group positioning evolve and are influenced by collective cognition. Third, it also contributes to the still-inadequate understanding of the drivers of patent strategies and innovation trajectories.

The paper is organized as follows. In section two, we describe the patent co-citation methodologies employed; in section 3, we present the bibliometric results and provide a graphical representation of firms' and groups' proximities performed by multidimensional scaling (MDS) and cluster analysis; in section 4, we discuss embryonic results and offer some conclusions;

Theoretical background

Bibliometrics and patent citation analysis

Patent citation analysis is an academic set of bibliometric methods directly derived from methodology that seeks to link patents in the same way that science references link papers. Papers and patents are both research instruments that adopt citation-count measurement systems (Narin, 1994). Moreover, in bibliometrics, the use of a citation approach for the assessment of similarity for the classification of documents is a mature methodology, and for this reason, it is feasible to apply the citation analysis of bibliometrics to patent analysis (Zhao & Guan, 2013).

Patent co-citation analysis

Co-citation analysis is a measure of the frequency of how many times A and B units are co-cited by third earlier units such as papers, authors, institutions, and in our study patents, inventors, or assignees (Lai & Wu, 2005; Wang et al., 2011). The assumption of co-citation analysis is that documents that are frequently cited together cover closely related subject matter (Small, 1973; Narin, 1994). In this vein, the co-cited frequency of patents can be used to assess the similarities or relatedness and to post evaluation and less-subjective unobtrusive patent maps and classification systems (Lai & Wu, 2005). In bibliometrics, it is used to assess document similarities in order to analyze the intellectual structure of science studies and identify cluster specialties and sub-fields (McCain, 1990; Di Guardo & Harrigan, 2012; Di Stefano, Gambardella & Verona, 2012).

Methodology

Sample and unit of analysis selection

Our analysis, following the bibliometric co-citation and patent co-citation methods prescriptions (McCain, 1990; Wang et al., 2011; Di Guardo & Harrigan, 2012) and in order to correctly select the unit of analysis started by tracing the history of most relevant M&As and alliances automotive industry milestones. This allow us to consequently identify in Derwent database the standard and non standard assignees codes for the overall and intermediate periods and correctly formulate compound Derwent Innovation Index and Derwent World Patent Index search queries (Wang et al., 2011). We retrieved assignees patent bibliometrics and assignees patent citation counts and finally co-citation frequencies. Operationally, the compilation of the raw co-citation matrix and its conversion to correlation matrix allow us to run multivariate analysis and consequently interpreting the findings. In the case of academic bibliometric studies, the unit of analysis may consist of scientific articles, authors and institutions (Small, 1973). Symmetrically, in the study of citation behavior in the patent analysis, the unit of analysis can be identified by single patents, inventors, institutions or assignees (Lai & Wu, 2005). Our research aims to show the strategic positioning and similarities between the leading automotive companies by displaying and then comparing the entire period of time with three different timespans. For these reasons we adopted assignees as unit of research.

Starting from the OICA 2013 report ranking, we selected the top 80 global companies in the automotive industry of manufacturers based on the number of commercial, passenger, and industrial vehicles produced. We examined the companies' websites and identified the number of brands for each company and its automotive groups. In the Derwent database, we checked individually for brands, single companies and groups, and the number of patents of the application date for the period 1991 to 2013. In this way, we divided the commercial brands by independent enterprises capable of producing technology. Then we looked back across the brands' histories, alliances, and M&As that occurred in the years between 1991 and 2013. In addition, in order to avoid the traditional limitations due to strategic and formal changes in companies and group structures, Derwent provides a comprehensive data set of joint ventures drawn up within industries in the period considered. From the operational point of view and following the correct search strategy proposed by Wang et al. (2011), we did a screening of all potential Derwent codes, including those with a different denomination than the main automotive group, related to joint ventures and M&As. In the research, we took into consideration 14 joint ventures formalized during the period among 18 companies.

Then, we launched an investigation of patent bibliometrics and identified the number of citations of the top 60 car manufacturers. Furthermore, in the hope of exploring the potential effects of the crisis in the strategic positioning of technology groups, we considered these in conjunction with the Asian crisis of 1997 - 98 and just before the start of the crisis of 2007–2008. Moreover, we took into account the M&A histories that showed that in these three periods, the most influential automotive group changes were concentrated. By analyzing the three periods, it was possible to visualize the structural change trends of automotive world industry. Finally, through the multidimensional scaling, a methodology that reduces the complexity and allows the matrices of proximity of certain objects to be studied (Mc Cain, 1990), we displayed the shape and measure the density of automotive sector conformation.

Discussion of results

Patent co-citation

The analysis of co-citations highlights the strategic positioning of the 49 major technological automotive companies in the global market in the period 1991 to 2013, 28 of the main groups in the periods 1991 to 1997 and 1998 to 2004, and finally the 34 major groups between 2005 and 2013. During the full period, the unit of analysis is the single automaker, while in the three time spans it is the automotive group through the extraction of aggregate data. The analysis of the complete map and the trends and changes in technology portfolios in the three time spans, considering the M&A histories and joint ventures, are discussed below through the results of multidimensional scaling and cluster analysis.

MDS and Cluster Analyses

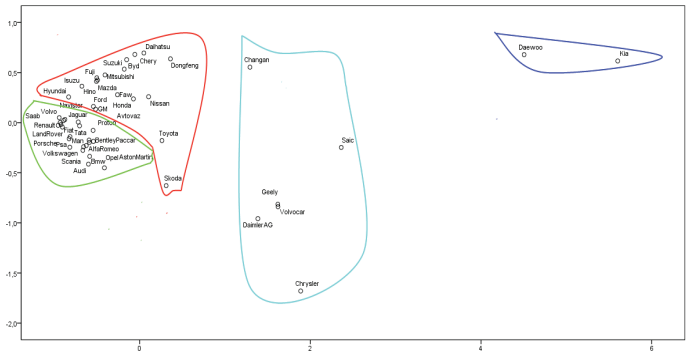

Figure 1. 1991-2013.

On the left of Figure 1 shows an area of high concentration and high technological similarities, while on the right, the distances among firms increase. In this scenario, cluster analysis clearly highlights four groups. The Japanese firms Toyota, Honda, and Nissan are the most central companies and belong to a larger international group comprised of Japanese, Chinese, Korean, and US companies. On the bottom left of the map, European manufacturers emerge, such as Volkswagen, Fiat, Porsche, Renault, BMW, PSA, and MAN, among which are India's Tata and the Soviet Avtovaz and the Malaysian Proton and its Lotus brand. Ford, GM, and Hyundai represent a technological bridge between the two areas. An important peculiarity of some company outliers such as Chrysler, Daimler AG, Geely, Volvo, and Chinese Saic and Dongfeng that belong to cluster 3 is seen, while peripheral positioning is occupied by Daewoo and Kia at the top right.

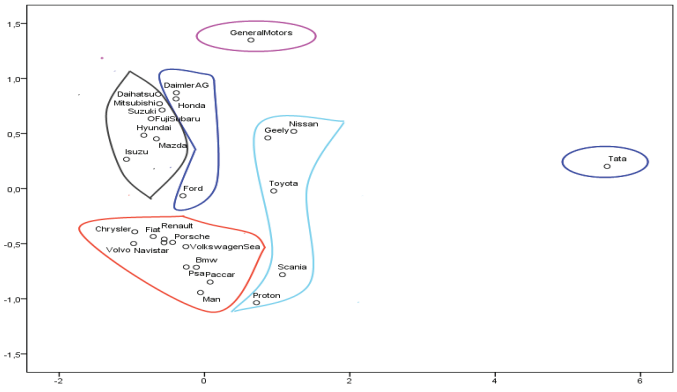

Figure 2. 1991-1997.

Figure 2 shows a major cognition concentration among firms, with the exception of the Indian company Tata on the right side. Ford, Toyota, and Renault are the major groups of centrality. Geely is the only Chinese enterprise present. Cluster analysis clearly shows six groups. General Motors is highly decentralized, a symptom of the uniqueness of its patent portfolio. Daimler and Hyundai are central, positioned in the two groups at the top along with the major Japanese companies, while at the bottom are MAN, Navistar, Volvo, and Paccar, which are all specialized in truck production, just below the European Union automakers. Interesting is the proximity of technology for Fiat and Chrysler, now belonging to the same group, and vice versa, the distance between Toyota and Daihatsu as separate companies at that time and since 1999 part of the same group. Of note is the proximity between Porsche and Volkswagen. Finally, the Volvo Group, at this stage not yet divided between truck and car production, is positioned at the left side near Navistar.

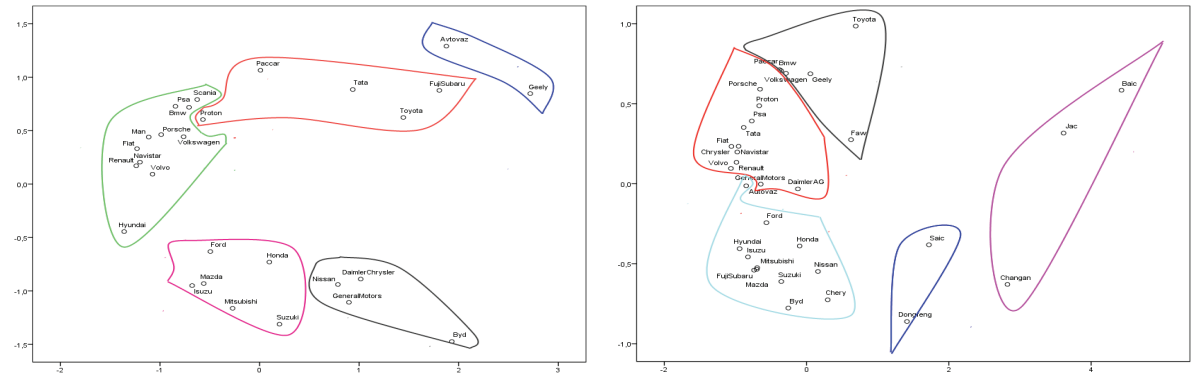

Figure 3. (a) 1998–2004. (b) 2005-2013.

Figure 3(a) transposes the effects of the Asian crisis of 1997-1998 and has a strong dispersion compared to the previous period's technology structures. The distances between companies are larger. To highlight the lack of a technological leader and a high level of technological heterogeneity, the central part of the map is empty.

Figure 3(b) includes the effects of the strong economic performance and global sales of the previous five years to have a stronger concentration symptomatic of technological proximity than in the previous period. During this period, Daimler AG, Ford, and GM occupy the most central locations on the map. General Motors, in particular, takes a decidedly opposite path in the three periods compared to Toyota. The American company tends to centralize its positioning technology, while Toyota tends to move within the confines of the map.

Conclusion and Limitations

This exploratory study increases the awareness of scholars by detecting and visualizing the cognitive structure, operationalized as companies' technological distances, of the automotive sector between 1991 and 2013. It reveals innovation similarities, technology positioning, and trends of assignees and groups, and makes it possible to hypothesize patent strategies and latent relationships among them. A contribution to the patent strategy and cognition literature has emerged on the basis of differences in positioning among companies and groups during the entire period and divided into time spans. In the overall map, this has emerged as some groups are composed of firms with heterogeneous positioning and consequently heterogeneous patent portfolios, while other groups have steadily increased over the years by acquiring high map closeness with companies with similar technological characteristics.

Second, the analysis of the three subdivided periods has highlighted how the level of similarity or distance among the groups, namely the collective cognition, changes continuously. The high concentration level that characterizes the first period is changed in the

second, which is more dispersed and where there are not central or technological leader groups. Yet the third one returns to a concentration level similar to the first period. Such behavior of the map, if considered in relation to the economic performance of the production and sales of the industry, reveals how, in times of crisis, companies tend to look for a heterogeneous technology portfolio to obtain competitive advantages, while in positive economic periods, conformity tends to prevail. It is as if the collective cognition profoundly affects the technology positioning and behavior of firms at the expense of objective assessments of patent strategy decisions. Third, research has highlighted significant strategic differences in positioning in the various periods in which such central enterprises move to the suburbs and vice versa, and some change their technology cluster membership by moving into another and finally emerge or disappear because of a failure or because of an M&A.

Fourth, an explorative contribution originates from the evaluative study of the groups' conformation in terms of brands and partnership formal contracts. In fact, it opens new horizons to researchers who want to analyze the impact of M&As or JVs on technological map positioning and, for example, in Foreign Direct Investments (FDI) and technology strategy literature. Finally, explorative findings of this study might be translated into managerial implications from the point of view of the companies strategic positioning planning. In fact, by detecting the heterogeneous technologies adoption (displayed by the more distant nodes in MDS), manager can potentially create innovative patent recombination strategies and consciously determine innovative future technological positioning scenarios.

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