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Technological trajectories in the automotive industry: are hydrogen technologies still a possibility?

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ABSTRACT

The integration of hydrogen technologies in the automotive industry as an option to cope with environmental issues has typically attracted significant attention among politicians, academics, and the media. After the recent "hydrogen hype" this interest in hydrogen technologies highlights the need to fully understand to what extent this sector is being pushed by new inventions. This paper presents a worldwide patent analysis of hydrogen technologies in the automotive sector. The study has been performed using a novel methodology by assessing trends of patents between 1990 and 2010 and their citations. As a result, we emphasize that the interest in hydrogen technologies has not declined over time and is mainly focusing on a small number of niches, although competing alternatives, such as electric vehicles, capture greater interest. Moreover, citation trends provide further insight into the development prospects of fuel cell and storage technologies as a point of convergence of multi-sectorial investments and, consequently, of potential R&D strategies in the automotive sector.

1. Introduction

To date, hydrogen technologies (HTs) are considered by several studies to be potential components of future energy systems (Amer and Daim, 2010). In particular, HTs have received a great deal of attention among politicians, academics and the media, especially between 1990 and 2006, when HTs were integrated into the automotive industry as an option to cope with its environmental impact (i.e. atmospheric emissions reductions, fuel consumption and noise) (Bakker et al., 2009). Despite energy balance assessments unanimously showing a poor life cycle energy performance of hydrogen-based mobility, studies on HTs are still part of the agenda of industries, research bodies and policymakers, in virtue of hydrogen's potential in the development of renewable energy storage, energy supply security and decentralization of the energy system.

There are, however, many unanswered questions about the technological life cycle of HTs. One of these surrounds the "chicken-egg" problem of whether the lack of infrastructures is the major barrier to alternative to vehicles that run on alternative fuels, or vice versa (Browne et al., 2012). Other important issues also play a role, such as the competition between hydrogen vehicles and fossil fuel internal combustion engines (ICEs) in traditional market segments, as well as the "technology race" (Ball and Wietschel, 2009; Browne et al., 2012) within the sector of electric vehicles in green market niches.

Within this context, after the recent "hydrogen hype," patent dynamics of HTs associated with the automotive industry are becoming quite relevant and call for deeper understanding (Bakker, 2010a). The aim of the present study is to analyze the worldwide trends in hydrogen inventions through a life-cycle perspective so as to improve understanding of the following: 1) the current relevance of HTs for the automotive industry and 2) current paths in the process of diversification of HTs. The "Background" section of this paper presents an overview of different approaches to patent analysis and describes the peculiarities of HTs in the automotive industry as the research setting. World-wide HT-related invention trends in the field of alternative fueled vehicles are here presented as a relevant issue for both methodology development and practical implications. The "Methodology" introduces a novel methodology for patent analysis based on trends and citations by describing the procedures and tools implemented. The "Results and Discussion" section shows the practicability of this methodology and highlight the heterogeneous vitality of different HTs in the automotive sector. Finally, we provide managerial and policy

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implications related to the development of HTs as an option for alternative fuel vehicles (AFVs).

2. Background

The use of patents as sources of information about technological progress has both advantages and disadvantages. The main advantage is that patents provide long-term and detailed technological information. The main disadvantages are that: simple patent counts do not take into account differences in technological quality; many patented inventions do not lead to innovations (i.e. are not applied) and the propensities to patent an invention may differ between sectors and firms (Verspagen, 2007).

Grounding on this premise, patents provide reliable information about trends in technologies and research and development (R&D) activities in order to support competitive analysis and technologies trend analysis (Abraham and Morita, 2001; Liu and Shyu, 1997). Therefore, analysis of patent data is considered a valuable method to assess technological changes and facilitate strategic planning efforts (Abraham and Morita, 2001).

Patent analysis can support the study of technological and economic development (Penrose, 1951; Taylor and Silberston, 1973), the assessment of R&D activities in a national and international context (Abraham and Morita, 2001; Paci and Sassu, 1997), analysis of the level of technological development in a particular sector from the perspective of firm policy (see Archibugi and Pianta (1996) and Basberg (1987) for patent analysis as a means to measure technological change; see Mogee (1991) and Liu and Shyu (1997) for patent analysis as a support for strategic planning), of technological strengths and weaknesses of competitors (Narin and Noma, 1987), and of foreign markets (Shipman, 1967).

Despite being a meaningful source of information, in the AFV sector there is a lack of studies which use patent analysis to define worldwide (historical) technological trends over a long period of time in order to provide information for establishing technological strategies in firms and policies. Geographical coverage, evolutionary nature and technology intensity are some of the characteristics that make AFV sector a suitable research setting for studying the following:

- Does a worldwide patent analysis represent a handy tool to define worldwide technological trends from a life cycle perspective?
- Do these technological trends provide firms and policymakers with useful information about potential directions for technology development?

Among AFV alternatives, HTs in the automotive industry have been in an “era of ferment” during which new technologies, in every stage of the supply chain (i.e. hydrogen production, storage, transport and conversion), have been developed and introduced into the already mature industry (Anderson and Tushman, 1990). Recent changes in attitude towards alternative fuels and HTs in the automotive industry have been triggered by the volatility of fuel prices, more stringent environmental legislation, new market demands and the maturation of new technologies (Orsato and Wells, 2007; van den Hoed, 2007; Magnusson and Berggren, 2011). In fact, in the United States the number of AFVs in use increased by 39.5% in the 2005–2009 period (U.S. Census Bureau, 2012).

In this sector, the development of alternative powertrain technologies necessarily induces the replacement of the existing ICE with a different system and requires new and massive investments (Zapata and Nieuwenhuis, 2010). Therefore, the automotive industry is facing uncertainty regarding the prospects, evolution and uptake of existing AFVs technologies (Contestabile et al., 2011) (i.e. flex-fuel vehicles, Hybrid Electric Vehicles, Electric Vehicles, Hydrogen Fuel Cell (FC) Vehicles, Hydrogen ICE vehicles, Liquid Petroleum Gas vehicles and Compressed Natural Gas vehicles). Each type of AFV technology can produce a different innovative effect on the ICE powertrain and the socio-economic environment (Hekkert et al., 2005; Sierzchula et al., 2012). In particular, HTs as possible options among AFVs have faced an overestimation in terms of cost reductions and driving range in the automotive industry during the previous decade. This overestimation, known as the “hydrogen hype”, produced disappointment which fostered the development of other AFVs such as Electric Vehicles (Bakker, 2010a). In fact, the prototypes of hydrogen passenger cars compared to current passenger cars are underperforming in terms of economic and technical efficiency (Romm, 2004). Therefore, world-wide HT-related invention trends are worth analyzing because HTs, including the different ways of production and use of hydrogen in cars, might be “prospective rather than actual technological options” (Bakker et al., 2012). In fact, car manufacturers have maintained diversified patent portfolios with different technological options for HTs (Bakker, 2010b; Oltra and Saint Jean, 2009) and have developed cross-company collaborations to share the development costs of HTs (e.g. BMW and Toyota; Daimler, Nissan and Ford; Honda and General Motors).

Based on the above considerations, HT patent data represent a suitable research setting for both testing tools for the analysis of long-term invention trends and advancing knowledge on sectorial AFV strategies.

3. Methodology

Our research design is based on patent data. It employed citation-based patent measures as a source of information on technological life cycles.

Having set the focus on the evolution of a specific technological field (i.e. HTs in the automotive sector), USPTO-granted patents represent a sound source of data (Pilkington, 2004). The USPTO dataset is considered comprehensive when it refers to relevant inventions. In fact, it is recognized that there is a relatively higher cost of patent applications in the US compared, for instance, to Japan. As a result, Japanese firms are known to patent a great deal in their own country for decoy reasons, but have more difficulty in patenting in the US (van den Hoed, 2005).

Moreover, the US patent law requires applicants to disclose prior art related to the invention in question (“duty of candor”) (von Wartburg et al., 2005). Michel and Bettels (2001) show that US patent applications require many more references than the applications of non-US patent offices.

Since the HTs are rapidly evolving and a patent has a limited life, nominally a maximum of 25 years in the US (Pilkington, 2004), a time span of 20 years for this study (1990–2010) has been considered as consistent with the goal of the analysis. The selection of the time boundary is also justified by the growth in technological variety and organizational competition, which coincides with the change in environmental policy implemented in the 1990s (e.g. the Californian Air Resources Board in 1990). The period 2011–2013 is not considered because in patent citation analysis the tendency for new patents to be less cited than old ones could prove to be a limitation when analyzing the recent years (Yoon and Kim, 2011).

The authors have developed a set of software instruments on an open source environment (i.e. Perl, Lazarus and Gnuplot under Linux) to assist with the patent search. The core of the set is a program capable of automatically interrogate major patent search engines such as FreePatentsOnline and Espacenet. Starting from a list of keywords and a set of options, the program conducts as many interrogations as needed to perform the requested analyses. The