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Leaving fossil fuels behind? An innovation system analysis of low carbon cars

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A B S T R A C T

The automobile industry faces increasing demands from society to reduce emissions from road vehicles. The objective of this paper is to assess whether the EU automobile industry has an appropriate innovation structure for R&D in low carbon vehicles and the role that public R&D policy can play. The Sectoral System of Innovation approach is used to map the innovation system. Then, the functions of the Technological Innovation System (TIS) framework are used to explore the innovation processes in the system. The analysis has shown that there is an effective innovation system, which may soon move into a growth phase of large scale technology diffusion. There is now a concentration of industrial research efforts on battery and hybrid electric vehicles. Since technologies such as fuel cells and composite materials have potential benefits, public R&D support may be needed to ensure their development in a range of relevant firms in the EU.

1. Introduction and scope of the analysis

The automobile industry is experiencing a period of turbulence and change. On the one hand, the car makers (or Original Equipment Manufacturers, OEMs) have low and variable profits, because they embody a mature technology in a globally competitive and mature market (Köhler et al., 2008; Orsato and Wells, 2007). On the other hand, the industry faces increasing demands from society to reduce emissions from road vehicles, especially greenhouse gas emissions (Whitmarsh and Köhler, 2010). This pressure is strengthening. EU policy is placing increasing emphasis on environmental concerns as well as the traditional policy agendas of economic growth and competitiveness, as is stated in the current Europe2020 strategy (European Commission, 2010). Innovations have a key role in helping the automobile industry to meet these challenges. Furthermore, automobiles are both a significant part of industrial output and employment in the EU,[2] but if the industry fails to innovate to meet these challenges there is a possibility that production and employment in the EU will contract (Bailey et al., 2010).

The main response of the automobile industry to these pressures so far has been the incremental improvement of energy efficiency of conventional internal combustion engines, helped by the market shift from gasoline to diesel cars in many European countries. In parallel, new forms of propulsion technologies have been researched, but so far these technologies have not yet taken a significant market share. However, in contrast to the previous episodes, the level of innovation activity has been increasing in more recent years with the advent of electric vehicles. All the major OEMs have now become active in one technology: electric drive with various types of hybrid ICE[3]-battery cars (HEVs), 'plug-in hybrids'(PHEVs), which can recharge their batteries from the electricity grid, or pure battery electric vehicles (BEVs) (Leduc et al., 2010). The main alternative technology considered for the longer term is hydrogen fuel cell vehicles (FCVs). Although biofuels are an important alternative, they do not require major innovation in cars themselves and are therefore not discussed in detail here even though the oil industry, specialised companies and many car manufacturers are actively engaged in the development of

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[1] The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

[2] In 2007 there were 834,000 jobs in Germany, 258,000 in France and over 100,000 in Italy, Spain, UK, the Czech Republic and Poland, a total of 2.3 Million in the EU 27 in 2007 (ACEA, 2010 quoting EUROSTAT data).

[3] ICE: Internal combustion engine (conventionally petrol or diesel).

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advanced biofuels. Lightweight materials are considered, but play a subsidiary role in the current developments.

Electric vehicles in particular have been developed in the past, both in the early 20th century and more recently in the 1960s and 1970s. Neither of these periods resulted in commercially successful electric cars. The current wave of development started in the 1990s (Köhler et al., 2008). Given the failure of previous attempts to develop a market in low emissions or electric vehicles, a critical look at innovation in the industry is required. An important question is whether the EU automobile industry has an appropriate innovation structure for R&D in low carbon vehicles and for the development of a mass market. The objective of this paper is to assess the innovation system for low-carbon vehicles of the European automotive industry. From this, we can draw conclusions on the potential role that public policy can play in either stimulating further innovation in the sector or in better aligning existing research with the objective of lowering CO_2 emissions.

Coenen and Díaz López (2010) survey and compare three frameworks that have been important in the analysis of innovation and sustainability: sectoral systems of innovation (SSI), technological innovation systems (TIS) and socio-technical (ST) systems. The TIS framework is an extension of the SSI framework to consider the development of a system of innovation through considering functions of innovation. Bergek et al. (2008) state that the TIS is intended to identify factors influencing the performance of the sectoral system of innovation. Coenen and Díaz López (2010) conclude that the TIS and ST frameworks are more appropriate for emerging demand and products, as is the case in low carbon automobiles. The ST framework has been developed to assess change to a new system, whereas the TIS has been developed to consider changes within a sectoral system of innovation. A corollary of this conclusion is that the ST framework is most appropriate for long run analyses, since a transition away from an established ST system will take a long time. In contrast, a TIS analysis is designed to consider the features of the current system. Since we have argued that low carbon automobiles are an innovation within the current paradigm of mobility, the TIS is the most appropriate framework for the analysis of whether this innovation system has the features necessary for expansion.

In the case of the automobile industry, EU and world production is dominated by a few large firms. These incumbents sell in all the major global markets and also develop their technologies for sale in all these markets. Therefore, although the analysis is intended to generate insights into innovation in the EU industry, developments in firms and markets outside the EU have to be considered. Carlsson and Stankiewicz (1991) show that a system of innovation and hence a TIS can be international.

There is an extensive literature on the engineering, economics and policy of low carbon technologies in cars (see Hensher and Button, 2003 for a comprehensive review). The concentration on propulsion technologies without changing the nature of provision of mobility can be seen as a limited response to the need for change. Vergragt and Brown (2007) identify the need for radical transformations to a new structure of mobility. They question the approach of developing hydrogen fuel cell powered vehicles and argue for a broader approach to alternative mobility, supported by new kinds of research. Köhler et al. (2008) survey the different firms' strategies in respect of environmental innovation. Different firms adopted different strategies with respect to different fuel and vehicle technologies and so no one firm can be readily categorized as a 'leader' or 'laggard' with respect to environmental innovation. Oltra and St. Jean (2009a,b) undertake a patent and policy analysis of the French automobile industry and find that the mix of environmental policy was not sufficient to shape innovation itself or the technological trajectory. Suurs et al. (2010) examine the TIS through 'motors of innovation' in the TIS for natural gas in cars in the Netherlands. They find that, while external influences are important, the internal development of the innovation system through mutual reinforcement of the different innovation functions in a TIS is also critical.

In this paper the SSI scheme of Kuhlman and Arnold (2001) is used to map the innovation system. Then, the functions of the TIS framework are used to explore the innovation processes in the system. These are used to asses the present effectiveness of the system and its potential to further develop low carbon technologies and markets. Implications for R&D policy are considered.

2. The structure of the innovation system

Fig. 1 shows the application of the structure of Kuhlman and Arnold (2001) to innovation for low-carbon cars. This structure was developed through a review of the literature on innovation in the automobile industry (see Leduc et al., 2010 for details) and discussed with stakeholders at a series of workshops organised through the EU FP7 project GHG-TransPoRD. Three sub-systems (industry, education and research, political) together form the core of the innovation system. The figure shows the industrial system structured around the OEMs. The purpose of this structure is to identify the various actors involved in the innovation process. The significance of the different actors for the success or otherwise of innovation in low carbon cars is discussed through the analysis of the TIS functions in section 3 below.

OEMs with their registered headquarters based in the EU are: VW-Audi, PSA Peugeot Citroën, Renault, Fiat, Daimler, and BMW. Smaller brands are owned by other international companies, with the US and Japan dominating, but Tata of India now own Land-Rover and Jaguar, and the new Southeast Asian manufacturers are also important international players. Chinese manufacturers are still not active at the global level, but are entering into cooperation agreements with the main manufacturers.

The OEMs have extensive networks of suppliers. The supply chain follows a pyramid structure with some large system (tier-1) suppliers such as Bosch, Valeo, ZF, or Continental. These companies in general have extensive own R&D activities, and sometimes coordinate smaller, often specialised companies active in the lower level of the supply chain.

There are some niche manufacturers of battery and high efficiency cars, such as Fisker or the Aixam with the Mega City EV, but these cannot be regarded as start-ups – if they are to produce vehicles, they already have considerable financial and human resources. Smaller than these small cars, new companies such as Segway are now producing and demonstrating electric micro vehicles, equivalent to scooters with battery power.

Due to the close interrelation between cars (and engines) and fuels, energy companies also have an important role in the innovation system. Traditionally these have been the oil companies and their fuel supply chain and infrastructure, which have not had a major role in car development. However, an important element of low-carbon innovation comes through the involvement of specialist companies in battery, fuel cell and energy storage technologies such as the application of Carbon Nanotubes to enable ultracapacitors to be practicable for vehicle power systems (Popular Mechanics, 2008). Associated with electric vehicles, power generation companies such as E.ON and RWE are active in developing battery charging infrastructure. The OEMs have had to enter into closer relationships with energy companies.

Universities and research institutes are also involved in the development of new automobile technologies, usually under contract to industry. Independent research institutes carry out applied research under contract in areas such as aerodynamics, control and driver support systems, design support software and