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How competitive forces sustain electric vehicle development

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ABSTRACT

This patent study researches the relation between competitive forces and the continuation of waves of Low Emission Vehicle (LEV) development. The competitive forces included are rivalry, dispersion referring to competition in general, and the presence of new entrants. We identify four waves of LEV development over the period 1990–2010, two of which were broken before becoming a commercial success, one that was continued, and one that is the current wave of Battery Electric Vehicle (BEV) development. Although the presence of new entrants could not be tested for all cases, our findings suggest that the combination of rivalry and dispersion positively relates to continued LEV development. We conclude that continuation of the current wave of BEV development is likely, as it is supported by increases in rivalry, dispersion and the presence of new entrants.

1. Introduction

In the mobility system, emissions from internal combustion engine vehicles (ICEVs) have significant impacts on climate change and on the atmosphere, e.g. through smog formation [1]. It is therefore important that the mobility system becomes more sustainable. Within the portfolio of technologies that are developed to attain a sustainable mobility system, technologies such as the Battery Electric Vehicle (BEV), the Hydrogen Fuel Cell Vehicle (HFCV), and the Hybrid Electric Vehicle (HEV), present a good alternative to the established ICEV [2]. We classify these technologies as Low Emission Vehicles (LEVs). Each of these LEVs contains a partial or full electric drivetrain and constitutes a technology that is significantly different from the established ICEV. These solutions have gained increasing attention and are becoming ever better developed [3,4].

Competence-destroying LEVs like the BEV and HFCV that render obsolete established ICEV technology [5] have enjoyed a trend of increasing attention and decades of technological development [6,7], though they have not experienced commercial success.[1] On the one hand, this is due to the established ICEV, which automotive firms have continuously developed to make it cheaper and more sustainable [3]. On the other hand, however, the failure of these competence-destroying LEVs can be explained by their pattern of development, which has always been characterized by hypes: periods of increased optimism succeeded by periods of disappointment. In this paper we focus on hypes to explain the presence and absence of LEVs' commercial success. We refer to the periods of increased technological development that accompany these hypes as 'waves of LEV development'. Waves of development are broken due to a successive period of disappointment [8]. A notable exception is the HEV. The technology is less competence-destroying and the wave of development is continued, leading to actual diffusion of this technology in the market and commercial success [9].

Another wave of LEV development has recently emerged. After the high hopes for hydrogen as a fuel plummeted in the last 5 years, the new hope of the automotive sector seems to be the BEV. Several car manufacturers are testing BEVs and

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[1] Although no recent successes have been attained, until the early 1900s more BEVs were sold than there were ICEVs [10].

investment decisions have been made to build factories. But it is uncertain whether this is just another hype that will be accompanied by disillusion in the near future, or whether this wave of technological development will actually become a continued one that may lead to commercial success.

To assess the chances of success of a new technology, in most cases technological characteristics and price developments are used. In earlier hypes of LEVs we witnessed intense disagreement between technological experts on expected technological performance and price developments [10,11]. Therefore, in this study we take another approach. We assess how the industry structure develops around emerging LEVs. Ceteris paribus, our basic assumption is that when an increased number and higher diversity of firms move into a new trajectory leading to more technological competition, the new technology is more likely to be continuously developed, improving its chances of commercial success. This relation between competition and innovation draws on an extensive body of literature that describes a positive relation between competition and continued technological development [12,13]. Literature also shows that this applies to LEV development [9,14,15].

These competitive forces can be broken down into different dimensions. It is important to distinguish 1) the level of rivalry between car manufacturers, 2) the level of dispersion: the extent to which different types of organizations contribute to technological development and 3) the presence of new entrants. This unprecedented set of dimensions draws from Technology Life Cycle literature [13] and builds on previous LEV studies [16].

In this article we first test whether the presumed positive correlations between these forces and continued technological development hold for three waves of technological LEV development. Subsequently, we analyze how these competitive forces relate to the fourth and current wave of BEV development to assess if continued technological development is now more likely to occur than during previous waves. Consequently, our research question is as follows: "*How did the forces of rivalry, dispersion and the presence of new entrants affect the duration of earlier waves of LEV development and how do these competitive forces affect the chances of continuation of the current wave of BEV development?*"

In this paper we study the relationship between competitive forces and waves of LEV development through patents. We analyze the technological fields of BEV, HEV and HFCV. In this patent study we intend to make four additions to the existing literature. Three are related to the literature on LEV forecasting and one to the general literature on technological forecasting.

- First, the timeframe of study comprises the period 1990–2010, enabling us to study the contemporary wave of BEV development that falls outside the timeframe of most previous studies [3,7,14].
- Second, we relate LEV development to a set of competitive forces not studied before and in doing so we broaden the scope of research outside the frequently studied population of large car manufacturers [3,7,14].
- Third, we not only use the conventional search queries applied in previous studies, but also add search queries on the component level of an LEV to enhance the capture of relevant patents, which results in a more comprehensive study of technology development.
- Fourth, we develop a set of indicators that are useful for technological forecasting. Until now, very little attention has been given in forecasting literature to using data on technological competition in order to assess future technological developments.

The remainder of this paper is structured as follows. In Section 2 we first elaborate on the waves of LEV development in the period 1990–2010 and subsequently describe how the competitive forces positively influence continuation of waves of LEV development. In the subsequent methodology section we elaborate on the research design and methods of data collection and analysis. We present the results and analysis in Section 4. Finally, in Section 5 we provide some conclusions, a discussion and some recommendations for further research.

2. Theoretical framework

This study on waves of technological development lies embedded within the larger body of literature that focuses on technological change. Perhaps the most well-known theoretical model is the Product Life Cycle (PLC), which is intertwined with industry and technology life cycles [5,17,18]. The PLC describes a cyclical process of transition where a radical innovation introduces an era of ferment, which is ended by the emergence of a dominant design that initiates an era of incremental innovation, which in turn is ended by the next radical innovation [5,17,18]. In the automotive industry, research shows that the LEVs under study are still in the era of ferment [9,19], whereas the ICEV has been the mature technology that was improved by incremental innovation for decades. Our study on waves of LEV development lies embedded within the PLC's era of ferment, which so far left these development dynamics largely unaccounted for. The PLC stresses that competitive forces play an important role in facilitating the development of emerging technologies like LEVs, especially in their era of ferment [5,17,18]. Consequently, in this theory section we discuss the relation between waves of technological development and a set of competitive forces to make predictions about the continuation of these waves of development.

2.1. Waves of development

The period 1990–2010 experienced four waves of LEV development. The first wave concerns the broken wave of BEV development in the early nineties [20,21] and was initiated by the demonstration of GM's working BEV prototype, the EV1.[2] Other large car manufacturers quickly followed GM with increased investments in BEV development and assembled their own working BEV prototypes [20,21]. However, this period was followed by a period of disappointment. High costs and low range were reported as technological showstoppers. The second broken wave comprised the development of HFCVs from the late 1990s to the mid 2000s [14,22]. This wave was

[2] The demonstration of this working prototype is argued to have triggered the Zero Emission Vehicle mandate by the Californian Air Resources Board as an important stimulus for LEV development [43].