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Catching recurring waves: Low-emission vehicles, international policy developments and firm innovation strategies

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ABSTRACT

Low-emission vehicle (LEV) technologies have grown in the 1990s, but have since experienced fluctuating interest. Initially, electric vehicles (EVs) were the most promising technology. Most large car firms developed EVs and started bringing them to the market, in limited numbers. Yet, car firms halted their EV engagement around 2001 and focused on hybrid vehicles (HVs) and fuel-cell vehicles (FCVs) instead. Hybrids found their way into the product portfolios of most car manufacturers while FCVs failed to gain traction. In 2006, car firms again committed to EVs, and on a larger scale. To better understand recurring waves of firms' low-emission-vehicle investments in the international context, this paper explores the influence of geographically-bound government policies on car firms' innovation strategies. An analysis of archival data from 1997 to 2010 details LEV-specific developments per region/firm, and shows the complex interplay between policies on local, national and international levels and firms' strategies. Three mechanisms seem to shape the international LEV trajectory: (1) international policy diffusion (vertically and horizontally), (2) firms' international operations, and (3) fit between policy requirements and firm capabilities. Heeding the call for a better geographical conceptualization of technological trajectories, this paper also proposes a framework that explains co-evolution between government policies and car manufacturers.

1. Introduction

Since 1990, car manufacturers have invested in cleaner engines, launched 'green' concept cars, and tested all kinds of other technologies to reduce car emissions (Pilkington and Dyerson, 2006; Oltra and Saint Jean, 2009). Three low-emission vehicle (LEV) technologies have emerged as potential alternatives for the internal combustion engine (ICE): hybrid vehicles (HVs), electric vehicles (EVs) and fuel-cell vehicles (FCVs) (Frenken et al., 2004). Interestingly, over time, the car industry went through different periods in which either EVs, HVs or FCVs were considered as the most likely substitute for the ICE (Bakker et al., 2012; Dijk et al., 2013; Wesseling et al., 2014). In the 1990s, EVs were seen as most promising. Most large car firms developed EVs and started bringing them to the market, in limited numbers. Yet, these firms halted their EV engagement around 2001—mainly because limited progress was made with battery technologies (i.e. high price, low range, long recharging time)—and invested in hybrids and fuel-cell vehicles instead (Dijk et al., 2013). HVs found their way into the product portfolios of most car manufacturers, while FCVs failed to get traction due to cost and infrastructure challenges. Yet, from 2006 onwards, car firms again started committing investments to EVs (Bakker et al., 2012; Bohnsack et al., 2014), partly due to renewed expectations that batteries would improve substantially following the rise of lithium-ion batteries as dominant technology (Pohl and Yarime, 2012; Magnusson and Berggren, 2011).

A growing body of literature in innovation studies has documented the emergence of LEVs (Dijk et al., 2013; Wesseling

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et al., 2014; Dyerson and Pilkington, 2005); investigating technological developments to develop alternatives for the ICE (Cowan and Hulten, 1996; Zapata and Nieuwenhuis, 2010a; Christensen, 2011) and competition amongst alternative LEV technologies (Frenken et al., 2004; Bakker et al., 2012; Wesseling et al., 2014; Bento, 2010; Berggren et al., 2009). Many studies regard government policy as the driving force behind car manufacturers' engagements in LEVs (Pilkington and Dyerson, 2006; Van Bree et al., 2010; Zapata and Nieuwenhuis, 2010b; Köhler et al., 2013), although the role of customers has been highlighted as well (Dijk and Yarime, 2010; Sushandoyo and Magnusson, 2012). Through technological standards, subsidies and tax incentives, governments provide a supportive environment for technology investments and customer adoption, and therefore they are most often seen as central in the transition towards sustainable mobility (Van Bree et al., 2010). While some of the existing literature has explored the link between policies, firm innovation and LEV development, it has most often focused on a particular single-country context. With a few exceptions (Sushandoyo and Magnusson, 2012; Åhman, 2006; Dechezleprêtre et al., 2014), scholars have paid less attention to the fact that car manufacturers operate internationally (Pohl and Yarime, 2012; Köhler et al., 2013) and are exposed to, and deal with, different policy interventions in various geographical areas at the same time (Pinkse and Kolk, 2012). This paper argues that the international nature of the car industry has important implications for governments' impact on corporate investments in LEVs. Therefore, and to better understand the recurring waves in the LEV trajectory, it explores the influence of geographically-bound government policies on firms' innovation strategies, seeking to uncover mechanisms that may explain why certain policies have had influence beyond their geographical boundaries while others have not. While considering findings from existing single-country studies, the paper adds a more comprehensive exploration of international developments of LEVs based on archival data collected for the period between 1997 (the year in which the first LEVs were commercialized) to 2010 (for further details see the Methodology and sample section). This research heeds the call for adding a spatial dimension to the perspective on sustainability transitions in the socio-technical systems literature (Coenen et al., 2012). From that body of knowledge, the paper also draws on a co-evolution perspective (Van Bree et al., 2010; Dijk and Yarime, 2010; Geels, 2002, 2006), as explained in the next section that briefly discusses the literature on the influence of government policy on firm innovation in an LEV context.

2. Underlying dynamics of the LEV trajectory: government–firm interactions

The majority of studies on the development of LEVs argue that car manufacturers, governments and customers are key actors (Pilkington and Dyerson, 2006; Dijk and Yarime, 2010; Sushandoyo and Magnusson, 2012). In this paper, we zoom in on the relationship between two of these actors—car firms and governments—as we are interested in the influence of policy instruments at different geographical levels on firm innovation strategies. As certain policy instruments, such as purchasing incentives, target customers, we deal with the role of customers indirectly; that is, only when such incentives have been important in driving firm strategies. Government policies are widely regarded as the trigger for car manufacturers to engage in LEVs, but there is much debate about their effectiveness in having a lasting impact on LEV market adoption (Zapata and Nieuwenhuis, 2010a; Pilkington et al., 2002; Van den Hoed, 2007; Hekkert and Van den Hoed, 2004).

2.1. Policy instruments and their impact on firm LEV innovation

Many studies have explored the government policy impact on LEV development, addressing the effectiveness of different policy instruments, distinguishing between command-and-control, market-based, and voluntary policy instruments (Kemp and Pontoglio, 2011; Bergek and Berggren, 2014). In the implementation of such instruments, there are distinctive cross-country patterns. Historically, the US used to have a bias towards command-and-control policies (Lee et al., 2010, 2011; Gerard and Lave, 2005), later complemented by market-based incentives and voluntary programmes (Gallagher and Muehlegger, 2011; Diamond, 2009). In comparison, European and Japanese governments used to employ a more collaborative policy style based on market-based and voluntary policy instruments (Mikler, 2010). However, over time governments in these regions have also started to use command-and-control policies through performance standards for local pollutants and carbon dioxide (CO_2) (Köhler et al., 2013).

The US were the first to regulate car emissions, using command-and-control policies based on performance standards (Bergek and Berggren, 2014; Lee et al., 2010). The 1970 US Clean Air Act (CAA), which implemented restrictions on car pollutants including hydrocarbons (HC), carbon monoxide (CO) and later also nitrogen oxide (NO_x), drove firm innovation in and adoption of catalyst converters in the 1970s and 1980s. While the CAA was a performance standard, given that the catalyst converter was the only viable technology, it essentially operated as a technology standard (Lee et al., 2010). The same pattern occurred two decades later when California implemented the ZEV (zero-emission vehicle) regulation, requiring a total reduction of local car pollutants for a share of cars sold. Car firms could only comply when they developed electric vehicles; hence, it was essentially a technology push for EVs (Bergek and Berggren, 2014). In terms of effectiveness, studies present evidence that technology-forcing regulations have been pivotal in directing the industry's innovation trajectory towards more radical emission-reducing technologies (Bergek and Berggren, 2014; Lee et al., 2010, 2011). However, it has been noted that forcing technology was only effective when firms had already made first steps in developing viable technologies themselves, such as catalyst converters and electric vehicles. Enforcing technological breakthroughs is far more difficult, and when governments have made attempts to do so, the industry response has been one of lobbying to drag or abolish performance standards (Gerard and Lave, 2005).

During the 2000s, attention shifted from local car pollutants to global CO_2 emissions (Dijk et al., 2013; Pohl and Yarime, 2012). To tackle global emissions, industrialized countries implemented performance standards; the US focusing on corporate average fuel economy (CAFE) and Europe on CO_2 emissions (Bergek and Berggren, 2014). Countries also adopted market-based instruments such as purchasing incentives based on sales tax waivers and income tax credits (Sierzchula et al.,