UvA-DARE (Digital Academic Repository)

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

Bohnsack, R.; Kolk, A.; Pinkse, J.

DOI

[10.1016/j.techfore.2015.06.020](https://doi.org/10.1016/j.techfore.2015.06.020)

Publication date

2015

Document Version

Final published version

Published in

Technological Forecasting & Social Change

License

Article 25fa Dutch Copyright Act

[Link to publication](#)

Citation for published version (APA):

Bohnsack, R., Kolk, A., & Pinkse, J. (2015). Catching recurring waves: Low-emission vehicles, international policy developments and firm innovation strategies. *Technological Forecasting & Social Change*, 98, 71-87. <https://doi.org/10.1016/j.techfore.2015.06.020>

General rights

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <https://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

UvA-DARE is a service provided by the library of the University of Amsterdam (<https://dare.uva.nl>)

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

René Bohnsack^a, Ans Kolk^a, Jonatan Pinkse^{b,*}

^a University of Amsterdam Business School, The Netherlands, Plantage Muidergracht 12, 1018 TV Amsterdam, The Netherlands

^b Manchester Institute of Innovation Research, Manchester Business School, University of Manchester, Manchester M20 6PB, United Kingdom

ARTICLE INFO

Article history:

Received 31 August 2013

Received in revised form 4 February 2015

Accepted 20 June 2015

Available online 30 June 2015

Keywords:

Low-emission vehicles

International policy

Firm innovation

Co-evolution

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.

© 2015 Elsevier Inc. All rights reserved.

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

* Corresponding author. Tel.: +44 161 275 7375.

E-mail addresses: r.bohnsack@uva.nl (R. Bohnsack), akolk@uva.nl (A. Kolk), jonatan.pinkse@mbs.ac.uk (J. Pinkse).

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 (CO₂) (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 CO₂ 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 CO₂ emissions (Bergek and Berggren, 2014). Countries also adopted market-based instruments such as purchasing incentives based on sales tax waivers and income tax credits (Sierczula et al.,

2014; Ross Morrow et al., 2010). US-based evidence from two studies about the effectiveness of financial incentives for US customers' hybrid technology adoption show mixed results (Diamond, 2009; Gallagher and Muehlegger, 2011). While incentives that bring down upfront costs, such as a sales tax waiver, have been more effective than incentives that have an effect over time such as an income tax credit, the overall impact of purchasing incentives on HV adoption seems limited. Instead, fuel prices were having more impact in the US. A more recent cross-country study shows that financial incentives have had an impact on the adoption of (plug-in) EVs in various countries, but the provision of a recharging infrastructure seemed more important (Sierczula et al., 2014). Market incentives have been implemented on different levels of government; while in Europe incentives tend to be implemented on a national level; in the US the level of the state is more common. A congestion charge is another market-based instrument that has been applied on a local level, and there is evidence that such charges in the European cities of London and Stockholm were fairly effective in stimulating LEV adoption (Nykqvist and Whitmarsh, 2008). Besides, government procurement has been employed to stimulate the market for LEVs. The local government agency Transport for London has played a pivotal role in this regard, by stimulating the diffusion of hybrid buses for public transport (Sushandoyo and Magnusson, 2012; Bergek and Berggren, 2014).

Along with command-and-control and market-based policies, governments have implemented a wide range of voluntary agreements (or public–private partnerships). While some voluntary agreements have been used as an alternative for a regulated performance standard, more often firms have cooperated voluntarily with governments in research development and demonstration (RD&D) projects to test LEV technologies (Köhler et al., 2013; Bergek and Berggren, 2014). A notable example of the former was the European Car Manufacturing Association (ACEA) agreement in which the European car industry agreed with the European Commission to voluntarily reduce CO₂ emissions (similar agreements were made with the Japan Automobile Manufacturers Association and the Korea Automobile Manufacturers Association). Since it became evident, after several reviews, that the agreement was failing to bring down car-related CO₂ emissions, it was converted into a mandatory performance standard in 2009 (Köhler et al., 2013; Pinkse et al., 2014). In Japan, the Ministry of International Trade and Industry (MITI) has also favoured a voluntary approach, but there it led to compliance as firms did not want to risk being excluded from receiving benefits from the Ministry in return (Åhman, 2006).

RD&D projects in the form of public–private partnerships are the more common voluntary instrument used for LEV development and have a long history in the car industry (Cowan and Hulten, 1996). Such projects' effectiveness is difficult to establish because they tend to be used in the early stages of technology development. Especially for the more radical LEV technologies, such as FCVs and to a lesser extent EVs, government-led research projects have been important to provide funding. In the US, for example, the Big Three (GM, Ford and Chrysler) were engaged in the Partnership for the New Generation Vehicle (PNGV)—later replaced by a programme called FreedomCAR—which did not have direct success. Interestingly, the PNGV did stimulate Toyota to further

develop the hybrid Prius, since it was not allowed to participate in this US-based programme, and thus had an unintended, indirect impact (Pinkse et al., 2014).

Since the 1970s, the Japanese government has also initiated several RD&D projects for EVs. These projects have created a local knowledge base and spill-overs within and beyond the car industry, as other firms such as battery producers were also included (Åhman, 2006). It has been argued that knowledge developed in these projects was later leveraged in HV development. Still doubts have been raised about the effectiveness of these Japanese programmes, also because, unlike the US-based programmes, the relationship between the government and the industry was not as close. Competition between Japanese car firms seems to have been a more important driver (Pohl and Yarime, 2012). A Toyota representative stated that the government has always been lagging behind RD&D developments within the car industry, and thus merely followed the strategies of car firms (Mikler, 2007). It has also been noted that the impact of government RD&D goes down, the more strategic LEVs become, because corporate RD&D budgets far outstrip what the government provides (Köhler et al., 2013). Still, the knowledge spillovers between firms might be the more valuable impact instead (Åhman, 2006; Pinkse et al., 2014).

2.2. An international perspective on policy impact

As the previous section showed, governments at different levels have contributed to the LEV trajectory by employing numerous policy instruments over time. Scholars studying the impact of environmental policies on car manufacturers' LEV engagement have mostly focused on single-country contexts. What has remained underexplored in these studies, however, is that car firms operate internationally (Pohl and Yarime, 2012; Köhler et al., 2013) and are exposed to a variety of government policies at different levels (Pinkse and Kolk, 2012). As Bergek and Berggren [116] recently stated: "Instruments implemented in one country can, of course, stimulate innovation in other countries, especially when supply-chains are international. This implies that the innovation impact of some instruments might be underestimated if the geographical scope of the analysis is too narrow."

Still, an international perspective has not been completely absent. Dechezleprêtre and colleagues (Dechezleprêtre et al., 2014), for example, studied the impact of environmental regulation on cross-border diffusion of technologies. Yet, their main focus was on the impact of regulatory distance, i.e. the difference in degree of stringency between countries, instead of on the differences between policy instruments. Some other studies also hint at the cross-border impact of policies without going into much further detail (Åhman, 2006; Lee et al., 2011; Sushandoyo and Magnusson, 2014). Most notable is the link between Japan and the US in this regard, due to the large market share of Japanese car firms in the US (Pohl and Yarime, 2012; Åhman, 2006; Gerard and Lave, 2005). Not only did this Japanese share of the US car market mean that US policies might have been more important for these firms, but the Japanese government also acknowledged this and deliberately tried to copy US policies. This pattern occurred in the 1970s, when Japan started regulating local car pollutants with the underlying reason to help domestic firms to be better able to comply with the regulatory demands in the US market (Gerard

and Lave, 2005), as well as in the 1990s when the Californian ZEV regulation gave a push the Japanese BPEV programme (Åhman, 2006).

One of the reasons for copying policies is that, even though car firms can be affected by government policies in foreign countries, they most often cannot benefit from the protective nature of these policies. Domestic firms tend to benefit more from local linkages with the government and institutions such as research institutes and universities (Lee et al., 2011). The Japanese government implemented policies domestically to enable Japanese firms to better compete in foreign markets (Åhman, 2006; Gerard and Lave, 2005). Another example of international linkages happened in the case of Volvo's development of hybrid buses for public transport. Volvo initiated its hybrid bus project using public funding from three Swedish RD&D programmes, but only developed it further through the field tests set up by Transport for London. After the success of the London tests, Volvo also engaged in similar tests in Paris, Gothenburg and Stockholm (Sushandoyo and Magnusson, 2014). What this specific example shows is that international linkages between policies can also occur on a local level with cities influencing one another. While the literature suggests that government policies have affected LEV development, and there are some indications that the international nature of the car industry is important in this regard, the international dynamics have not been studied in a more comprehensive way so far.

2.3. Towards a co-evolutionary perspective on the international LEV trajectory

A perspective to analyse the influence of government policy on firm LEV innovation in an international context is the co-evolution framework, which has been developed in the socio-technical systems literature (Geels, 2002). Within a social-technical system, the linkages between actors such as consumers, car manufacturers and governments form a socio-technical regime (Geels, 2004). Although the relative stability of a regime over time is one of the main assumptions underlying this perspective, it is possible for a new socio-technical system such as LEVs to emerge, albeit gradually (Schot and Geels, 2007). Several factors can destabilize the regime and initiate more radical changes, such as technological breakthroughs, new regulations, and shifts in customer preferences (Geels, 2002). The transition process is accelerated when such dynamics move in parallel (Schot and Geels, 2007). Promising breakthrough technologies often occur in niches, which are protected spaces that shield these technologies from mainstream development and market selection mechanisms (Schot and Geels, 2007).

The co-evolution perspective has been a popular lens for exploring LEV developments (Whitmarsh, 2012). Van Bree et al. (2010) utilized the perspective to develop transition scenarios for FCVs and EVs. Oltra and Saint Jean (2009) studied the co-evolution between car manufacturers' innovation strategies and competition amongst different LEV technologies. To understand the emergence of EVs, Dijk and Yarime (2010) examined the co-evolution of supply (i.e. car manufacturers) and demand (i.e. consumers). They derived four key co-evolutionary mechanisms that shape the LEV trajectory: scale economies, learning about the market, social construction of LEV connotation, and network effects. Yet, their study regarded

policymakers as an external force to co-evolution, rather than as co-evolving itself (Dijk and Yarime, 2010).

These studies pay little attention to the international nature of the LEV trajectory, however. As explained in the previous sections, many governments have designed policy measures to foster LEV development which shape local dynamics (Mikler, 2005). This has created various local co-evolutionary developments that together form an international LEV trajectory. While studies on LEVs have not focused on the international perspective, overall studies in the socio-technical systems literature have also paid little attention to the spatial dimension. Coenen et al. [p. 968] asserted that “analyses have often neglected where transitions take place, and the spatial configurations and dynamics of the networks within which transitions evolve.” In view of the distinctive spatial patterns of policy instruments used across countries, some co-evolutionary mechanisms remained within specific geographical boundaries, while others have been boundary spanning instead. In the remainder of the paper, we are especially interested in the latter and will try to understand why certain policies have had influence beyond their geographical boundaries and thus a stronger bearing on the international LEV trajectory.

3. Methodology and sample

This study analyses the international LEV trajectory using a longitudinal approach. Since the main objective is to understand how multiple policy interventions affect firm innovation strategies, we collected qualitative process data, which “consist largely of stories about what happened and who did what when—that is, events, activities, and choices ordered over time” [Langley, 1999, p. 692]. Using process data, we aimed to identify patterns in how firms engage in innovation. In addition, this would help to provide a more comprehensive account of the LEV trajectory from an international perspective.

As concrete illustration of, and background for, this international focus, Table 1 provides an overview of the sales of the 20 largest car manufacturers from Europe, Japan and the US, representing 95% of the sales in these areas in 2000 and 89% of the world's car production in that year. These three hubs were the main areas of the car industry in which almost 89% of new vehicles were sold (Mikler, 2005). The table illustrates that, generally, car manufacturers dominated their home markets. Domestic car manufacturers in Europe contributed 77% of all sold cars in their home area, while this amounted to 68% in the US and up to 95% in Japan. Interestingly, Japanese car manufacturers also had a 26% share of the US market (equivalent to 4.4 million cars). In fact, the majority of the Japanese manufacturers (e.g. Honda, Mazda, Mitsubishi, Nissan, Toyota) sold in absolute terms even more cars in the US than in their home country, highlighting the importance of US regulation for Japanese car manufacturers (Åhman, 2006). Japanese car manufacturers also held a 13% share of the European market, but overall sold more cars in Japan.

The European car manufacturers, on the other hand, had smaller shares in the US. Only the luxury car manufacturers BMW and Daimler (Mercedes, Smart) had considerable shares, but sold less than in their home area. Volkswagen, Volvo and Saab also had lower shares in the US market. Sales by foreign car manufacturers in Japan were negligible (less than 6%). Consequently, Japanese regulation was less central for US and

Table 1

Sales in the three lead markets of the largest car manufacturers in 2000.

Car manufacturers sorted by origin	Sales in Western Europe	% of combined sales	Sales in Japan ^a	% of combined sales	Sales in the US	% of combined sales	Combined sales in 2000
<i>Europe</i>							
BMW	499,000	69%	36,000	5%	188,000	26%	723,000
Daimler (Mercedes, Smart)	811,000	68%	51,000	4%	336,000	28%	1,198,000
Opel	1,508,000	100%	–	0%	–	0%	1,508,000
Fiat (all)	1,475,000	100%	1800	0%	–	0%	1,476,800
Peugeot (Peugeot, Citroen)	1,929,000	99%	11,000	1%	–	0%	1,940,000
Renault	1,559,000	100%	2000	0%	–	0%	1,561,000
Saab	79,000	65%	2800	2%	39,000	32%	120,800
Volvo	230,000	63%	15,500	4%	122,000	33%	367,500
VW	2,756,000	85%	58,000	2%	436,000	13%	3,250,000
Sub-total	10,846,000	77% ^a	178,125	4% ^a	1,121,000	7% ^a	
<i>US</i>							
Chrysler	97,000	4%	7500	0%	2,522,000	96%	2,626,500
Ford	1,247,000	24%	7600	0%	4,021,000	76%	5,275,600
GM	6600	0%	4900	0%	4,981,000	100%	4,992,500
Sub-total	1,350,658	10% ^a	20,000	1% ^a	11,524,000	68% ^a	
<i>Japan</i>							
Daihatsu	–	0%	385,000	100%	–	0%	385,000
Honda	182,000	9%	691,000	34%	1,159,000	57%	2,032,000
Hyundai	227,000	48%	–	0%	244,000	52%	471,000
Mazda	181,000	26%	253,000	37%	254,000	37%	688,000
Mitsubishi	160,000	21%	296,000	38%	315,000	41%	771,000
Nissan	393,000	24%	502,000	30%	751,000	46%	1,646,000
Suzuki	131,000	21%	424,000	69%	60,000	10%	615,000
Toyota	542,000	16%	1,216,000	36%	1,620,000	48%	3,378,000
Sub-total	1,816,000	13% ^a	3,767,000	95% ^a	4,403,000	26% ^a	
Total	14,012,600	40%	3,965,100	11%	17,048,000	49%	35,025,700
Total area sales in 2000	14,746,571	40%	4,259,872	12%	17,811,673	48%	36,818,116
Sample % or area sales	95%		93%		96%		95%
World production							41,215,653
% of World production							89%

Sources:

European data: ACEA, new vehicle registrations by manufacturer, historical series: 1990–2012 http://www.acea.be/images/uploads/files/20120806_06_PC_90-12_By_Manufacturer_W_Europe.xls (accessed 24-10-2012).

Japanese data: Japan Automobile Manufacturers Association Inc., Motor vehicle Statistics of Japan (2012) <http://www.jama-english.jp/publications/MVS2012.pdf> (accessed 23/10/2012).

US data: Based on WardsAuto data: www.wardsauto.com/keydata/historical/UsaSa28summary.xls.

www.wardsauto.com/keydata/historical/UsaSa01summary.xls (accessed 23/10/2012).

World data: <http://www.worldometers.info/cars/> (accessed 23/10/2012).

^a % of area sales.

European car manufacturers. US manufacturers operated mainly in their home country. Only Ford and GM—through its European subsidiary Opel—also had a large share in Europe. While this indicates that the home country was most important for most car manufacturers, it also shows that the industry was internationally connected. The varying degrees of importance of home and host markets for car manufacturers make this study an interesting case to see how particular countries and firms affected the international LEV trajectory.

We collected data from two trade magazines—*Automotive News* and *WardsAuto World*—and a car magazine—*Autoweek*—as they focus on the car industry and can provide insight into industry and corporate perceptions by offering rich descriptions of technologies, developments within firms, and the relevant policies. Furthermore, we chose the *Financial Times* because of its focus on business strategies and attention to environmental issues in the broader political and economic context. Both newspaper and magazine articles are seen as a stable source, given that they existed prior to the start of the case study and provide good insight into the main themes of interest for this

paper and allow gaining robust data for triangulation (Yin, 2009). We performed a keyword search for the period 1997–2010, using search terms from the different LEV technologies—i.e., hybrid, electric vehicle and fuel cell—generating a dataset of 9908 articles over a 14-year period. Before the database was compiled, we first tested different search terms in a pre-study, using terms such as electric car, hydrogen car or hydrogen vehicle. In the pre-study, the different terms showed no significant differences in the search results over the years, which led us to focus on the three search terms for our study. We adopted a global reading approach for all articles and coded the relevant articles. The year 1997 was used because in that year the first LEVs were brought to the market. Moreover, 1997 saw the adoption of the Kyoto Protocol, which formalized international action against climate change. It added to the uncertainty of car manufacturers because their products contribute significantly to CO₂ emissions. Fig. 1 shows the distribution of the articles over the years by source.

To analyse the articles, we used the qualitative data-analysis software Atlas.ti 6.2, which can manage large datasets and

Fig. 1. Distribution of articles in the dataset by year and source.

Table 2

Announced LEV activities by firms' area/country of origin, types and phases.

Period	1997				1998–2005				2006–2010				Grand total
Type	US	EU	JP	Total	US	EU	JP	Total	US	EU	JP	Total	
HV	2	2	4	8	29	9	33	71	15	22	39	76	155
EV (incl. PL)	3	–	8	11	3	1	6	10	24	22	25	71	92
FCV	–	1	–	1	18	9	24	51	6	5	10	21	73
Total	5	3	12	20	50	19	63	132	45	49	74	168	320

enables users to define the length of selected quotations and fully capture the richness of the information. We followed a three-step approach for the data analysis. In the first stage, we analysed which technologies car firms engaged in (i.e. hybrid vehicles, electric vehicles or fuel cell vehicles) and examined up to which stage the cars were developed (i.e. concept car including prototype, test car or mass produced car).¹ This

¹ Concepts are used to present technologies or designs but are not intended for production. It should be noted that, in this study, concepts and prototypes were aggregated, with both terms being used interchangeably because the analysis suggested blurring boundaries between concept cars and prototypes. Prototypes are usually the preliminary models of a new car to experiment with novel technologies. However, concepts were also often used to assess new technologies. Test cars encompass vehicles that are examined under controlled, real-world conditions to learn from and improve the technology based on a wider test group. Mass-produced cars were assumed when car manufacturers had a dedicated production line in place for standardized products.

generated a list of 320 LEVs that were announced between 1997 and 2010 (see Table 2). Although triangulating the data against corporate websites showed no inconsistencies, the results may not be complete as it is based on secondary sources.

As Table 2 shows, from 1997 to 2010, 29 car manufacturers were investing in LEVs and launched in total 320 different LEV models; most were concept cars or prototypes (221), some were test cars (39) and others were mass produced (60). In the studied period, the engagement of car manufacturers in LEVs increased over the years (see Fig. 2), with about 23 LEVs, on average, developed per year. The lowest number of LEVs was developed in 1998 (11) and the highest in 2009 (45). Most LEVs were HVs (155), followed by EVs (92) and FCVs (73), indicating a general dominance of HVs, which is likely due to their less radical character compared to EVs and FCVs.

Fig. 2. Announced LEVs per year by type. (Labelling of phases taken from Bakker et al. 2012; data collected by authors).

In the second stage of the data analysis we tracked all relevant policy interventions found in the dataset (e.g. command-and-control, market-based and voluntary instruments) in different geographical areas—i.e. countries and regions—at different policy levels—i.e. local, national and international. All events present in the dataset were coded and subsequently integrated in the analysis based on their subjective relevance for the LEV trajectory. This was decided based upon the frequency, the reaction of stakeholders and, in case of doubt, discussed amongst the authors. In the third stage, we tracked how policy interventions affected firm innovation by linking policy interventions with car manufacturers' LEV engagement, analysing the effects of policy interventions over time. We then combined all interactions into a matrix and identified patterns. Based on the matrix, we generated narrative descriptions of the effects over time and across areas (Bourgeois and Eisenhardt, 1988). Finally, the narrative was juxtaposed with the relevant literature, and refined accordingly.

4. The evolution of the LEV trajectory from 1997 to 2010

In the following, we will provide an account of the interplay between different government policies and firm innovation and its impact on the LEV trajectory. Overall, the findings that emerged from our data² show that LEV activity increased over time, with changing foci on different LEV technologies. The

analysis also suggests that activity differed considerably, not only between manufacturers from different geographical areas, but also within each area per manufacturer (see Table 3). These geographical patterns imply that the international LEV trajectory is not only a result of technological developments, but also of policy interventions. Before analysing the underlying mechanisms that have steered the international LEV trajectory, this section first provides a brief description of the most important developments within this trajectory from 1997 until 2010.

Various studies have described the evolution of LEVs (Bakker et al., 2012; Dijk et al., 2013; Wesseling et al., 2014) and the different stages in which the evolution evolved. In our analysis of the factors that influenced the turns in the trajectory we follow Bakker et al.'s (2012) phases in LEV development. On the basis of article counts of battery-electric and hydrogen vehicles, they labelled the phase until 1997 as 'exploring batteries', 1998–2005 as 'the rise of hydrogen', and 2006–2009 as 'the revival of electric'. Different from their two-fold distinction, however, this study further breaks down the category of battery-electric vehicles into electric, hybrid and plug-in (PI) vehicles. Moreover, we discuss the phases based on actual LEVs launched, not on the number of articles on specific technologies.

For the first phase, our data show that until 1997 car manufacturers focused on batteries in various forms (EVs, HVs and PIs), thus confirming Bakker et al. (2012). Car manufacturers for the first time launched LEVs on a larger scale and experimented with LEV technologies, particularly 'exploring batteries'. Table 4 indicates that more than half (55%) of all LEVs presented were EVs (including PIs), while HVs represented 40%. The FCV share was still small (5%). Table 2 (see above)

² Given the large number of sources for the findings presented here, the article does not provide detailed references of all statements except for direct quotes and links to the broader literature. These are marked with an asterisk in the reference list. Full referencing is available from the authors upon request.

Table 3

LEVs developed per firm and technology from 1997 until 2010.

Car manufacturer	HV	PI	EV	FCV	Total
<i>US</i>					
Chrysler	10	3	4	5	22
Fisker	–	1	–	–	1
Ford	12	3	4	6	25
GM	24	8	4	13	49
Tesla	–	–	3	–	3
Total	46	15	15	24	100
<i>EU</i>					
BMW	4	1	3	3	11
Daimler	9	3	4	7	23
Ferrari	1	–	–	–	1
Fiat	1	–	1	–	2
Peugeot	4	–	2	3	9
Porsche	3	–	–	–	3
Volvo	1	1	1	–	3
VW	6	1	2	2	11
Total	29	6	13	15	63
<i>Asia</i>					
BYD	–	2	2	–	4
Daihatsu	–	–	–	1	1
Great Wall Motors	1	–	1	–	2
Honda	17	–	2	9	28
Hyundai	9	1	–	4	14
Kia	2	–	1	1	4
Mazda	3	–	–	4	7
Mitsubishi	2	1	4	2	9
Nissan	9	2	10	3	24
Renault	3	–	4	–	7
Saab	1	–	–	–	1
SAIC	1	–	–	–	1
Subaru	4	1	–	–	5
Suzuki	1	1	3	2	7
Tata	–	–	1	–	1
Toyota	27	3	4	8	42
Total	80	11	32	34	157
Grand total	155	32	60	73	320

further illustrates that especially Japanese and US firms engaged in LEVs with a focus on EVs (8 and 3 developed EVs respectively). European firms only developed two EVs and one FCV. Table 3 shows that the majority of LEVs was developed by Japanese firms (12), followed by US (5) manufacturers, while European car manufacturers only developed 3 LEVs.

In the second phase, 1998–2005, EV development almost halted and car manufacturers focused on FCVs and HVs. Only 7% of all LEVs were EVs, the remaining 93% were HVs (54%) and FCVs (39%). The large difference between firms' EV and HV engagement emphasizes the value of distinguishing the two LEV technologies rather than aggregating them as battery-electric vehicles. It provides a more nuanced picture of the technology development, and shows that HVs had a solid share. In this phase, HVs and FCVs competed for the dominant LEV design position (Hekkert and Van den Hoed, 2004). Still, due to the more incremental nature of HVs, these cars were making

Table 4

Share of announced LEVs developed in the phases of the LEV trajectory.

Period	1997	1998–2005	2006–2010
Hybrid	40%	54%	45%
Electric (incl. PI)	55%	7%	42%
Fuel cell	5%	39%	13%

Table 5

Announced LEVs by development stage.

2006–2010				
Area/type	Concept	Test	Mass produced	Total
<i>US</i>				
HV	3	0	12	15
EV (incl. PI)	17	4	3	24
FCV	4	2	0	6
Total	24	6	15	45
<i>EU</i>				
HV	16	1	5	22
EV (incl. PI)	18	4	0	22
FCV	4	1	0	5
Total	38	6	5	49
<i>JP</i>				
HV	21	2	16	39
EV (incl. PI)	16	5	4	25
FCV	6	2	2	10
Total	43	9	22	74
Grand total	105	21	42	168

their way already into the mass market, while FCVs predominantly remained in the test stage (see Table 5). Japanese and US firms were leading with US firms developing 50 LEVs (29 HVs, 18 FCVs and 3 EVs) and Japanese firms developing 63 LEVs (33 HVs, 24 FCVs and 6 EVs). European firms were less engaged with only 19 LEVs (9 HVs, 9 FCVs and 1 EV).

The third phase, 2006–2010, shifted the LEV trajectory back to EVs. The financial crisis, tightening fuel-efficiency standards, reduced battery prices due to increasing production capacity, and urban interest in pollution-free alternatives triggered a new search for alternative technologies reflected in increasing launches of EVs and PIs. In this phase, 42% of all LEVs were EVs (including PIs), a sharp increase from the small share in the previous phase; while FCVs and HVs lost 26% and 9% of the overall market share, respectively (see Table 2). With the introduction of plug-ins and the renewed EV interest, the popularity of FCVs waned, confirming the fear that PIs could close the market for FCVs (Bento, 2010). In this period 71 of the 92 EVs (including PIs) were developed (see Table 5). Japanese firms stayed in the lead, developing 74 LEVs (39 HVs, 25 EVs and 10 FCVs), but there was now also increasing activity of European manufacturers, bringing 49 LEVs to the market (22 HVs, 22 EVs and 5 FCVs), which was more than US firms (15 HVs, 24 EVs and 6 FCVs). While Japanese firms focused on HVs (39), US firms put relatively more emphasis on EVs (24), and European firms invested in HVs and EVs equally (with 22 models of each type). Hybrids became mainstream in this period (see Fig. 2) and almost all car manufacturers integrated HVs into their product portfolios. Nissan intended to sell more than 50,000 HVs in 2006, while Daimler decided in 2008 to integrate hybrids into their whole line-up. Even luxury car manufacturers, such as Porsche and Ferrari, started to develop HVs, also to counter urban penalties for high emissions and to adapt to the now mandatory fuel-efficiency targets in Europe (Köhler et al., 2013; Pinkse et al., 2014).

5. Mechanisms stimulating international LEV diffusion

What emerges from the short account of the LEV trajectory is not only that the focus on different LEV technologies changed

over time, but also that the focus and the intensity of engagement differed across countries. In the following, we shed light on the role of the ‘government policy–firm strategy’ interface in shaping the international LEV trajectory. Patterns in our data suggest three mechanisms that have influenced the international LEV trajectory: international policy diffusion, international operations of firms and the fit between policy requirements and firm capabilities. First we will explore the mechanisms individually, to then explain how they are interconnected.

5.1. International policy diffusion

The first mechanism that influences the LEV trajectory is *international policy diffusion*. Policy diffusion has been defined as “one government’s choices being influenced by the choices of other governments” [Moynihan, 2012, p. 1]. We found that policies have diffused in two directions: vertically between levels of government as well as horizontally between countries.

Much of the current research on policy diffusion has focused on vertical diffusion, looking at top-down and bottom-up diffusion of policies. A landmark event with a top-down impact was the 1997 Kyoto Protocol, which aimed to constrain greenhouse gas emissions, including CO₂. To meet their Kyoto commitment, many countries tightened fuel-efficiency regulations because CO₂ emissions correlate with fuel consumption (Dijk et al., 2013). While the Kyoto Protocol had little direct impact on car manufacturers, since emissions trading schemes—the main policy instrument used—had a marginal impact on car firms, it had an indirect one. Mobility-related CO₂ emissions were considered as one of the main causes of climate change, and concomitant policy interventions started to surface. In Japan, for example, concern with the Kyoto commitment led to the Top Runner programme (Lau et al., 2009), and to the voluntary ACEA agreement in Europe (Hovi et al., 2003). Besides, this international framework for climate change stimulated general environmental awareness, resulting in a change in customer preferences towards more efficient cars (Achtnicht, 2012).

One of the most significant bottom-up policy diffusion events occurred in California. The implementation of the ZEV programme by the California Air Resource Board (CARB) in 1990 was a major trigger for the LEV trajectory (Pilkington et al., 2002; Pinkse et al., 2014). This programme required car manufacturers to have 2% of their sales to be ZEVs beginning in 1998, a share required to grow to 10% by 2003. CARB in general and the ZEV programme in particular had a huge influence on car producers given that the state of California is one of the biggest and most profitable car markets in the world. The programme intended to reduce air pollution in California, which was suffering from severe smog problems in metropolitan areas. As California’s car industry was not significant in the 1980s, the ZEV programme was also regarded as a way to stimulate the local economy, providing jobs in a knowledge-intensive industry (Schot et al., 1994). The ZEV programme was not only influential because of the size of the market, but also because regulation from California was often adopted by other US states or countries, for example in case of the catalytic converter (Gerard and Lave, 2005). This is also why GM and DaimlerChrysler filed lawsuits against CARB to stop the ZEV programme. For example, in the lawsuit, “GM contend[ed] that

CARB ha[d] not considered other alternatives for cleaning automotive pollution nor weighed the minimal demand for EVs as seen in their first offering in the late ‘90s. GM executives expressed worry that the CARB mandate would be picked up by three Northeast states, thus affecting nearly 20% of the U.S. light-vehicle market” [Rechlin, 2001, p.1]. The ZEV programme was eventually modified, and car manufacturers were allowed to comply with credits earned by selling small golf-cart-like EVs or hybrids.³ While the ZEV programme was too ambitious for car manufacturers, it was successful in raising awareness of LEVs. In fact, many other US states did try to adopt the ZEV regulation, but were stopped by court injunctions.

What has made the ZEV programme influential was not only that it could be diffused to the federal level, imposing performance standards across the US, but also that it has been emulated in other countries and thus diffuse horizontally. There appear to be two motives for such horizontal policy diffusion between countries. On the one hand, policies are diffused across countries because they seem to present a competitive threat, e.g. because they target an industry which is strategically important (Porter and van der Linde, 1995); on the other hand, policies are diffused if they successfully tackle a problem (Busch and Jörgens, 2005). With regard to the competitive threat, the ZEV programme influenced policy measures in other countries with significant car industries, as it pushed Japan to adopt its BPEV (Battery Powered Electric Vehicle) expansion plan and triggered Germany to conduct a large-scale EV test on the island of Rugen. To avoid a competitive lead and support the local industry in developing the necessary capabilities to comply with California’s requirements, these countries implemented similar programmes through which domestic car manufacturers could develop and test these technologies in their home market.

A horizontal ‘rat race’ between countries has also occurred with regard to fuel cell technology. In 1999, CARB began stimulating FCV development through the California Fuel Cell Partnership (CaFCP), by providing a refuelling infrastructure and enabling manufacturers to test FCV technologies. CaFCP inspired other public RD&D projects, such as the Japan Hydrogen & Fuel Cell (JHFC) demonstration project and the Clean Energy Partnership (CEP) in Germany. One reason for the German government to reinstate its FCV technology funding (there had been a high level of funding from the 1970s to the 1990s (Budde et al., 2012)) were expectations that the US and Japan were gaining a lead, a competitive threat it tried to counter. The main argument used by FCV proponents in Germany to lobby the government for extra funding was the potential job loss in the German car industry (Budde et al., 2012).

As mentioned, policies also diffuse if they successfully tackle a problem. In particular, the Japanese Top Runner programme (see Section 5.3.1) and purchasing incentive programme were considered successful. Other countries emulated the Japanese approach of incentivizing LEVs, with the US implementing tax incentives on a state level. Also during the financial crisis many countries implemented similar support programmes for LEVs (e.g. tax incentives). California, for instance, allowed HVs in the

³ Subsequently, many car manufacturers, including Daimler and GM, offered neighbourhood electric vehicles (NEVs), and some dropped out of EV projects altogether. For example, Ford divested Think, an EV manufacturer it had bought earlier, and invested in hybrids instead.

carpool lane followed by other US states. In London, HVs were exempted from the newly introduced congestion charge. This practice—already in place in Singapore—inspired other urban areas to limit access to city centres through measures like the ‘environmental zones’ in large German cities (‘Umweltzonen’).

5.2. International operations of firms

The second mechanism that we found to influence the LEV trajectory is the *international operations of firms*. Different local co-evolutionary trajectories between governments and firms interacted because car manufacturers operated in different international markets. Although Table 1 indicates that car manufacturers have traditionally focused on their home markets, most were present in various markets and thus connected geographical areas. Areas with LEV policies in place and in which many foreign car manufacturers operated (e.g. California) affected car manufacturers beyond their borders and had a larger influence on the international LEV trajectory than areas in which few foreign players operated (e.g. Japan). Equally, car manufacturers that operated in various areas (e.g. Toyota) were affected by several policies in home and host markets, and appeared to be more influential on the international LEV trajectory than firms that focused largely on their home market (e.g. Peugeot).

To illustrate, Toyota, like many Japanese car manufacturers, had large market shares in Japan and the US and was equally exposed to policies in these areas. When California allowed the use of credits from HVs to comply with the ZEV regulation, Toyota and Honda also began selling HVs in California, which were until then only available in Japan. As Åhman [p. 439] stated: “Toyota, Nissan and Honda were all affected by the Californian ZEV mandate and now entered the BPEV development race more seriously than before and began investing heavily in BPEV technology.” The car manufacturers might have sold the HVs in California or the US also without the stimulating policy, yet this is unlikely as the cars were initially sold at a loss. Where the Japanese firms became pivotal in the international diffusion of hybrids,⁴ for FCV technology the role of cross-border ambassador was shared amongst firms from different countries. For example, Daimler (generally considered as leader in FCV technology), Ford, GM and Toyota were all participating in fuel-cell partnerships—i.e. CaFCP, JHFC, and CEP—in three regions simultaneously.

The Californian ZEV programme also affected European car manufacturers. As Pilkington et al. [p. 7] argued: “European [...] automobile manufacturers faced the same restrictions from the CARB ZEV mandate, and so had also been developing EVs for both indigenous and export use.” The data analysis showed that especially the European car manufacturers Daimler and BMW developed LEVs as more than 25% of their sales were from the US (see Table 1). Likewise, car manufacturers from the US, Japan and Korea had larger shares in the European market. As there was no unified policy that stimulated LEVs until 2008, however, this market was relatively less influential for the international LEV trajectory. Only when various EU Member

States implemented incentives for LEVs in the wake of the financial crisis and mandatory EU targets for car-related CO₂ emissions were established, did European policy begin to influence the LEV trajectory. The adoption of these EU policies offered an opportunity for US and Japanese car firms to promote their technologies and in turn shape the LEV trajectory in Europe, where they were already active and could now leverage their home-market experience with LEV technologies.

Since car manufacturers operate internationally, competitors in international markets can be pressurized to engage in specific technologies. For instance, when Toyota found itself endowed with an innovative and green image following the successful launch of the Prius Two in 2003, US and European car manufacturers were subsequently criticized for the lack of hybrids in their line-ups. In order to catch up with Toyota's lead in HV technology, Daimler, GM and BMW decided to jointly develop their own full hybrid technology for the US market. Competition between domestic players has also been an important incentive for firms to pursue a specific LEV technology. Daimler's lead in FCV technology spurred BMW to also invest in cars using hydrogen as a fuel (Budde et al., 2012); and competition between the Japanese car firms has led them to become similar in geographical expansion and technology investments. Toyota and Honda moved almost in parallel in developing hybrids, and the launch of the Prius pushed Nissan to move into hybrids as well, so not to lose face in the eyes of Japanese society, even if they had difficulties to do so financially (Pohl and Yarime, 2012).

5.3. Fit between policy requirements and firm capabilities

While the first two mechanisms explain how markets are linked, whether internationally operating car manufacturers transfer technologies from home to host countries (and vice versa), and whether local/national policies stimulate policymakers abroad depends on a third mechanism: *fit between policy requirements and firm capabilities* (Pilkington, 1998). It is this third mechanism that explains to what extent the first two mechanisms spur the international diffusion of LEV technologies. When there is a good fit between regulatory requirements and firm capabilities, there is a larger chance that an LEV technology will be diffused across borders. What is important in this regard is whether government policy is demanding incremental or radical technology (Bergek and Berggren, 2014), since the latter is less likely to be part of the existing capabilities of car firms, thus causing at least an initial misfit (Pilkington, 1998). Table 6 distinguishes these two types of policy demands, which will be discussed consecutively, in relation to firms' capabilities.

5.3.1. Policies demanding incremental improvements

One policy instrument that has been demanding relatively incremental technological changes, and thus a high potential fit with firm capabilities, is a fuel-economy standard. Various countries implemented stricter fuel-efficiency standards at the beginning of the period under study. One of the first was Japan, which in 1999 implemented fuel-consumption standards under its Top Runner programme, demanding average fuel consumption per fleet of 16.8 km/l (125 g CO₂/km) by 2010. A fit between policy requirements and firm capabilities was reached due to Japanese manufacturers' successful lobbying to support LEVs

⁴ While Toyota has been most successful in hybrids, Honda had an important role in the cross-border diffusion of hybrid technology as it was the first to launch an HV in the US (Pohl and Yarime, 2012).

Table 6

The interaction between policy measures and firms' capabilities.

	Firms' technology focus	
	Incremental	Radical
Policies demanding incremental improvements		
Fuel economy standards CO ₂ emission standards (targeted at car producers)	1998: <i>(Voluntary) CO₂ regulation (EU)</i> Firms tried to comply partially with non-technology-related means 1998: <i>Top Runner programme (Japan)</i> Japanese car firms improved fuel efficiency and complied before 2010 2004: <i>CAFE increase for light-trucks (US)</i> Car manufacturers integrated HVs to meet CAFE standards	
High fuel taxes	2001: <i>UK car tax</i>	2003: <i>London congestion charge</i>
Fiscal incentives	Sales of diesels rose from 34% in 2001 to 70% in 2005	Car manufacturers started small LEV projects, such as Daimler tested 100 EVs in the city centre
Traffic control measures (targeted at car buyers)	1996: <i>BPEV Purchasing Incentive Programme (Japan) 2nd stage</i> Toyota sold more than 70,000 hybrids until 2000 2005: <i>US tax credits</i> Stimulated increasing engagement in HVs by almost all car manufacturers 2004: <i>Carpool- Lane Usage in California</i> Stimulated HV sales in California	
Policies demanding radical improvements		
RD&D programmes	2004: <i>ZEV programme</i>	1990: <i>ZEV programme</i>
Technology mandates and targets (targeted at car producers)	Stimulated hybrid development and more efficient ICEs Create scale for hybrids and fostered their international diffusion Car manufacturers stopped their engagement in ZEVs	The largest 6 car manufacturers brought a limited number of EVs to the market 1999: <i>California Fuel-Cell Partnership (CaFCP)</i> Various firms tested FCVs (DaimlerChrysler, General Motors, Hyundai, Honda, Nissan, Toyota, Volkswagen) 2001: <i>Clean Urban Transport for Europe</i> Firms tested hydrogen technology—e.g., Shell, BP, and DaimlerChrysler 2002: <i>FreedomCAR (US)</i> Resulted in no directly related cars 2002: <i>Clean Energy Partnership (CEP)</i> Car firms tested FCVs in Berlin 2002: <i>Japan Hydrogen & Fuel Cell Demonstration Project (JHFC—Japan)</i> Participating manufacturers tested their FCV technologies in test cars and obtained real-world driving information 1996: <i>BPEV Purchasing Incentive Programme (Japan)</i> Was targeted at EVs initially, but only 400 EV cars benefited, and programme had little influence.
Fiscal incentives (targeted at car buyers)		

with incentives such as a lower sales tax. Since Toyota and Honda had already developed hybrids, these firms could comply without extra effort and benefited directly from the incentives in further diffusing HV technology, also across borders. However, Nissan's capabilities did not have a fit with the policy to the same extent, as its hybrid programme was not as developed as that of its two domestic competitors. Nissan's CEO Carlos Ghosn argued: "We have the technology [...] But when I have seen the cost of the car I say, no way" [Autoweek, 2001, p. 4]. Japan met the Top Runner programme's 2010 targets in 2002, which led to an increase in the targets in 2006. Despite low penalties, car manufacturers complied even before the deadline, due to tax incentives and pride as the names of firms that failed to comply would be made public (Mikler, 2005).

In the US, the corporate response to fuel-efficiency standards was markedly different. The Corporate Average Fuel Economy standards (CAFE), first implemented in the 1970s in reaction to the oil crisis, had remained unchanged for three decades (Cheah and Heywood, 2016). To not penalize small-business owners, in its original setup CAFE had distinguished between cars and light trucks with cars having to meet 27.5 mpg and light trucks 20.7 mpg by 1996. Yet, because light trucks (e.g., SUVs) became increasingly popular as family cars, regulators now also targeted these, with the intention to increase the standard for light trucks to 21.0 mpg. Car firms lobbied heavily against further tightening CAFE, using their FCV involvement as an argument. GM claimed that CAFE did not support the transition towards sustainable mobility: "CAFE is actually an obstacle to the realization of this vision of hydrogen-based, clean, efficient, personal mobility" [Stoffer, 2002, p. 3]. Firms complained about a misfit between fuel-efficiency standards and their innovation strategy, as CAFE would not support the technological direction towards FCVs, they claimed to have taken. Despite the opposition, the new US Energy Act of 2007 required a fleet average of 35.5 mpg (equivalent to 6.6 l/100 km) by 2020 (from an average of 24.7 mpg in 2004), measures which were introduced stepwise.

The initial misfit in the US was restored already to some extent by 2003, as doubts were mounting regarding FCV costs and technological problems. Besides, car firms had not lived up to their promises of commercializing FCVs for the mass market. Therefore, the Big Three (GM, Ford and Chrysler) lobbied the federal government for tax incentives for hybrids. Chrysler announced wanting to make some profits on the technology and thus needed tax incentives: "We think the price premium will be \$3000. We think the cost is under that. But we have to make a little profit on it. Our strategy is to get the component set numbers up higher, drive the costs down and perhaps someday take the price premium below \$3000. We are also hoping and we're actually campaigning to get this \$3000 tax credit that was talked about last year" [Jewett and Truett, 2001, p. 26]. Not surprisingly, Toyota also lobbied for incentives in the US. Following industry pressure and the positive results of incentives on LEV diffusion in Japan, the Bush administration put in place HV tax credits of up to \$3400 in 2005. Still, not all members of industry saw such government support for HVs as a good fit with their strategy, and they raised doubts about the costs for the customer. While HVs appeared in the portfolios of manufacturers selling cars in the US, it was not necessarily because firms saw a mainstream market for them. As Ford's CEO Bill Ford stated: "If [hybrids] don't get customer

acceptance, I really don't know what we do next. [...] What our entire industry needs is government help. Hybrids are more costly. We know consumers have a very limited appetite for paying more for these vehicles" [Connelly, 2003, p. 16].

In Europe, government policy pushed for incremental changes as well, but as mentioned above, EU policy focused on CO₂ emissions instead of fuel economy. The voluntary ACEA agreement set targets to reduce car firms' fleet average CO₂ emissions per kilometre driven from the 1995 fleet average of 186 g CO₂/km to 140 g CO₂/km by 2008 (EC, 2009). While the policy requirement concerned the uptake of incremental technologies, it still failed to stimulate LEV diffusion. It was not only the voluntary nature of the agreement, which apparently failed to be a credible threat in the eyes of car firms, but also the prevalence of diesel technology in Europe. The large European firms had developed very efficient diesel engines, which were more promising for compliance with EU policy than EVs, HVs or FCVs. While EU policy could have stimulated further development of efficient diesel technology, it did not have the potential for international diffusion, due to a misfit with policies and customer preferences outside Europe. Leading European car firms such as Volkswagen and PSA Peugeot were not able to capitalize on their diesel technology outside Europe, because US and Japanese standards for particulate matter and NO_x were too strict, and diesel cars were not popular amongst customers in these markets.

Because the ACEA members failed to meet the voluntary targets, mandatory CO₂ emission targets were finally adopted in 2009. The regulation demanded that by 2015, European car manufacturers' fleet average had to be 130 g CO₂/km, but to ease the burden 120 g CO₂/km should come from vehicle technology, while the remaining 10 g CO₂/km could be realized with measures such as low-resistance tires, an easier and cheaper fix for car manufacturers. Starting in 2012, the EU phased in the targets, with 65% of the fleet needing to comply, using a stick and a carrot. The 'stick' was in the form of penalties for non-compliance per vehicle. For each gramme exceeding the target (after the 4th gramme), car manufacturers were charged €95, which could have severe financial consequences. The 'carrot' was given in the form of credits that could be earned with vehicles that emitted less than 50 g CO₂/km. Every so-called 'supercredit' was equivalent to 3.5 cars in 2012/13 (2.5 in 2014 and 1.5 in 2015, respectively). As a consequence, European car manufacturers finally started to significantly contribute to LEV development (see Table 2).

So while in all three regions, government policy demanding the implementation of incremental improvements started out as a misfit with firm innovation strategies, governments and firms found each other eventually. This process went much faster in Japan than in the US and the EU, respectively. Moreover, it was not until performance standards were accompanied by purchasing incentives that especially sales of hybrids started taking off.

5.3.2. Policies demanding radical improvements

For more radical demands, such as zero emissions, governments used RD&D programmes and mandatory technology standards. Various RD&D programmes were implemented to stimulate zero emission targets, which particularly focused on the development of FCV technology (e.g. the CaFCP, JHFC and CEP; see Table 6). These programmes provided platforms for

car manufacturers for international testing and learning (Harborne et al., 2007), and for mitigating the investment risks involved (Link and Scott, 2001). To develop FCVs, car manufacturers had to develop new capabilities and some participated in a small series of tests using conventional cars modified to implement the expensive but emission-free fuel-cell technology. The tests showed that while the technology was efficient, it was not practical in terms of costs and infrastructure. Only a few car firms participated in these tests and did not make the technology available internationally. Nonetheless, although the direct effect on the international diffusion of LEVs was marginal, it did stimulate research and provided an important learning platform for the technology (Link and Scott, 2001). So while the RD&D programmes had a good fit with the nascent state of technology development, it was due to high development costs and lacking infrastructure that FCVs failed to gain momentum.

Radical technology improvements were also mandated using technology standards. California's ZEV programme effectively mandated EVs (Bergek and Berggren, 2014), but was not very successful in making them mainstream. Despite initial support for the programme, car manufacturers were unable to make EVs commercially viable, as batteries remained expensive and driving range was too limited. Hence, the policy requirements seemed to outstretch what firms were capable of in terms

of technology development. Firms lobbied intensively to stop the programme, which resulted in a memorandum of understanding (MOU), obliging firms to put up to 3750 EVs on Californian roads between 1998 and 2000 (Shaheen et al., 2002). Only the largest car manufacturers in terms of sales in California—GM, Ford and Chrysler from the US, and Toyota, Honda, Nissan and Mazda from Japan—had to bring ZEVs to the market, and one of them—Mazda—even managed to avoid the MOU by purchasing credits for 138 cars from Ford.

After the agreed-upon EVs were on the road, all car manufacturers stopped producing more. An anonymous official of Honda provided the answer why: “The real question, if we were to keep selling the EV Plus, would be, ‘Are we moving forward? Are we advancing the technology?’ And the answer would be, ‘I think not.’” [Automotive News, 1999, p. 12]. In fact, after CARB relaxed its demands, many firms reclaimed the EVs and scrapped them. Ford raised concerns about whether such government mandates are beneficial: “What the electric Ranger experience did teach us is when we just do something either because regulators have asked us to do it or just to say we are there, there is really not much value to that” [Truett, 2001, p. 26].

However, California's performance standard started to affect the LEV trajectory to a greater extent in 2009, when it began stimulating existing capabilities, mainly plug-ins. Car manufacturers regarded PI development as the cheapest way to

Fig. 3. An international multi-level framework.

comply. Toyota argued that because of the “way California has set up the rules, plug-in hybrids would likely appear to be one of the lowest-cost ways to meet the requirements” [Truett, 2009, p. 3]. After adopting the policy, GM unveiled the Volt plug-in and announced its upcoming production, declaring that “[t]his is not a science project and not a public relations ploy” [Reed, 2007, p. 25]. Shortly afterwards, Toyota stated that it would work on a plug-in Prius, while Nissan and Mitsubishi announced mass production of fully electric vehicles, i.e. the Nissan Leaf and Mitsubishi iMiev. A similar pattern of easing policies, which initially demanded radical technologies, occurred with Japan's BPEV expansion plan. As such, this plan had very limited influence on the development of EVs in Japan (Pohl and Yarime, 2012). Only when it was adjusted in response to the Toyota Prius, did it start to have an impact on the diffusion of hybrids (Åhman, 2006).

Thus, policies requiring radical technologies, such as FCVs and EVs, had in and of itself limited direct impact on the international LEV trajectory (see Table 6). Nevertheless, firms engaged on a small scale in these technologies. Subsequently, governments toned down requirements—often after intensive lobbying—which then stimulated the more incremental technologies, such as HVs and PIs. These technologies had now come within reach by reusing know-how gained from trying to develop the more radical technologies. These ‘toned-down’ regulations had a significant influence on the international LEV diffusion as they laid the basis for mass-produced LEVs.

5.4. The emerging international LEV trajectory

Together, the three mechanisms—international policy diffusion, international operations of firms, and fit between policy requirements and firm capabilities—have been important in shaping the international LEV trajectory. Fig. 3 shows the dynamics between the different local/national LEV trajectories and how the mechanisms link them.

Considering Bakker's three phases again, the first phase ‘Exploring batteries’ was triggered largely by the ZEV programme in a local LEV trajectory, which was subsequently emulated in other car markets through international policy diffusion because of the strategic role of the Californian market. As these policies required radical technologies, there was a misfit with car manufacturers' capabilities in basically all the markets across the world and few LEVs were launched as a consequence. However, toned-down adaptations of the ZEV programme led to the increased diffusion of HVs and later PIs, locally as well as globally. Other policy developments that were initiated around the beginning of the period under study also had a sustained impact. The Kyoto Protocol affected fuel-efficiency and CO₂ standards and tax incentives in many countries; including in Japan, where it stimulated the Top Runner programme (Lau et al., 2009), for which requirements could be met with existing capabilities and thus pushed the diffusion of hybrids. Subsequently, car firms from Japan diffused hybrid technology to the US due to their international operations, the large market in the US, and the fit with local policies.

In the second phase, ‘Rise of hydrogen’, HVs competed against FCVs, the latter of which were stimulated by the CaFCP and the idea of a hydrogen economy. The CaFCP was diffused to other markets such as Japan and Germany due to the strategic

importance of the car industry. While there was a fit between policy requirements and car firms' capabilities, FCV technology was too immature for commercial viability and technological barriers were not overcome. HV technology, on the other hand, was picked up, and the various local LEV trajectories witnessed an increase in HV activities, which influenced the international LEV trajectory. This was also driven by market incentives and global events, such as the war in Iraq and hurricane Katrina, which led to surging fuel prices. The increased importance of hybrids also paved the way for a renewed interest in EVs, which led to the ‘Revival of electric’ phase. The global financial crisis of 2008 triggered various governments to support advanced green technologies, mostly EVs and later also plug-ins. Fig. 3 illustrates the linkages between the mechanisms; showing that a good fit, large markets and presence of internationally operating firms have a strong influence on the international LEV trajectory.

6. Discussion and conclusion

To better understand the recurring waves in the LEV trajectory, this paper 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. The basic argument emerging from this study is that the LEV trajectory—besides by technological developments—was shaped by the international co-evolution between policies in different geographical areas at different policy levels and car manufacturers' innovation strategies. This provides a new perspective on the LEV development since thus far scholars have largely focused on technological aspects (Bakker et al., 2012; Wesseling et al., 2014; Magnusson and Berggren, 2011; Bento, 2010). While some studies pointed to the relevance of government policies and firm innovation, they focused either on single countries or one specific technology only (Dyerson and Pilkington, 2005; Zapata and Nieuwenhuis, 2010a; Van Bree et al., 2010). Moreover, this paper has attempted to identify the mechanisms that underlie the international co-evolution between government policies and car manufacturers to shed light on the emergence of the international LEV trajectory, thereby responding to calls for more attention to such a spatial dimension (Coenen et al., 2012).

Accordingly, this paper makes two main contributions. First, it provides a more comprehensive perspective on the international LEV trajectory and sheds light on the underlying factors leading to recurring waves of interest in different LEVs. While drawing on the three phases identified by Bakker et al. (2012) based on a Dutch weekly car magazine, this paper enhances their findings by building on an expansive database compiled from four international sources. Moreover, rather than relying on article counts for specific technologies, this study is based on actual LEV launches. It furthermore extends Bakker et al.'s (2012) findings in that it considers all three LEV technologies rather than combining EVs and HVs into battery electric vehicles, thus presenting a more nuanced picture. The paper also pays attention to the government policy–firm interplay in different geographical areas and at different policy levels which illustrates the international interactions of car manufacturers and policymakers. Facilitated by favourable policies, LEVs have

carved out a significant niche in the market and gradually found more ways to escape the lock-in of the ICE, particularly through hybrids and plug-in EVs (Cowan and Hulten, 1996; Zapata and Nieuwenhuis, 2010a). Concomitantly, this paper shows that car manufacturers' focus on HVs and EVs locked out FCVs as an alternative LEV technology, thus substantiating earlier concerns of a pre-mature lock-in of a potentially suboptimal technology (Hekkert and Van den Hoed, 2004).

The second contribution of this paper is that it heeds the call for a spatial conceptualization in the socio-technical systems literature (Coenen et al., 2012; Carlsson, 2006). So far, scholars have paid limited attention to the geography of technological trajectories and tended to treat different geographical areas in which trajectories occur as one space (Coenen et al., 2012). Trajectories have been conceptualized as emerging in local niches that evolve into a global level (Geels and Raven, 2006); however, this conceptualisation does not necessarily refer to geographical areas but rather to the wider community of actors that are either directly (locally) or indirectly (globally) related to projects (Coenen et al., 2012). In short, the literature so far has insufficiently shown where technological trajectories are shaped and which mechanisms influence the trajectory across geographical areas. This paper proposes three mechanisms—international policy diffusion, international operations of firms, and fit between policy requirements and firm capabilities—that conceptualize how several local technological trajectories may shape an international trajectory.

These mechanisms enable a better understanding of the international co-evolution of technological trajectories and enrich the socio-technical systems literature by explaining co-evolution internationally between policies and firms. In doing so, the mechanisms fill the gap of insufficient spatial conceptualization in the socio-technical systems literature (Coenen et al., 2012). They increase the understanding of the role of different geographical areas, account for the diversity of transitions, and link the transition literature to existing research that investigates different spatial dimensions (Coenen et al., 2012). The mechanisms also answer a call by Whitmarsh (2012) to investigate mechanisms that link international with local developments, since “the two are inextricably linked and causality is bi-directional” [Whitmarsh, 2012, p. 485]. In summary, the international perspective of the mechanisms applied in this study adds to our understanding of the interplay of various international policies and firms in shaping transitions of more environmentally-friendly technologies.

Obviously, the study reported in this paper also has limitations. The analysis has focused mainly on the policy–firm interplay, thereby underexposing other factors such as consumer demand conditions. Also, inferring car manufacturers' reactions from policy measures and vice versa requires caution. Reactions of actors often have a time lag and are also influenced by a multitude of other internal and external factors, such as new entrants in the industry like Tesla or changes in adjacent industries like the battery industry. A further limitation is the reliance on secondary sources. Yet, “given the often highly secretive nature of new product development activities in the car industry and the highly emotive political atmosphere of these initiatives”, as Pilkington and Dyerson [p. 79] put it, this approach seemed the best available.

Due to these limitations, while all three emerged from patterns in the data, for some mechanisms the evidence was

more solid than for others. The occurrence of international policy diffusion was particularly evident in the case of vertical diffusion; in the US context, regulatory developments in California are explicitly linked to federal policy in the US, for example. Horizontal diffusion was not always as easy to establish, as governments do not always state that they emulate policies from other countries, even if they do. Still, the implementation of similar types of policies across countries with small time lags only clearly suggested that this mechanism is at play. Similarly, the relation between firms' geographic scope and their exposure to government policies was discernible with a high degree of certainty. The findings are more tentative with regard to the fit between policy requirements and firm capabilities as firms tend not to disclose whether their innovation activities are a direct response to policy or not. For strategic reasons, firms have the tendency to downplay the influence of the government on their activities, which does not mean the influence is not there. Besides, it is difficult to determine what the exact capabilities are of a firm, due to the highly secretive nature of innovation in the car industry. Still, we could observe a clear difference in firm responses to policies demanding radical improvements and incremental improvements, respectively, and firms referred themselves to whether policies were demanding improvements that could be achieved within a realistic timeframe.

We tried to address the shortcomings of using secondary data by drawing on different data sources to see if there was common agreement across them. Besides, we verified to what extent our findings concur with those of other studies in the field of LEV development. As mentioned, the general patterns were similar; by deriving three mechanisms that explain the reasons behind the development of the international LEV trajectory, we hope to have contributed to a better understanding of why and how the recurring waves of LEV development unfold.

References

- Achtnicht, M., 2012. German car buyers' willingness to pay to reduce CO₂ emissions. *Clim. Change*, 113, 679–697. <http://dx.doi.org/10.1007/s10584-011-0362-8>.
- Ahman, M., 2006. Government policy and the development of electric vehicles in Japan. *Energy Policy*, 34, 433–443.
- Automotive News, 1999. Honda delivers a strong vote against electrics. *Automot. News* 73, 12 (*).
- Autoweek, 2001. *The News*. Autoweek 51, 4 (*).
- Bakker, S., van Lente, H., Engels, R., 2012. Competition in a technological niche: the cars of the future. *Technol. Anal. Strateg. Manag.* 24, 421–434.
- Bento, N., 2010. Dynamic competition between plug-in hybrid and hydrogen fuel cell vehicles for personal transportation. *Int. J. Hydrogen Energy*, 35, 11271–11283.
- Bergek, A., Berggren, C., 2014. The impact of environmental policy instruments on innovation: a review of energy and automotive industry studies. *Ecol. Econ.* 106, 112–123. <http://dx.doi.org/10.1016/j.ecolecon.2014.07.016>.
- Berggren, C., Magnusson, T., Sushandoyo, D., 2009. Hybrids, diesel or both? The forgotten technological competition for sustainable solutions in the global automotive industry. *Int. J. Automot. Technol. Manag.* 9, 148–173.
- Bohnsack, R., Pinkse, J., Kolk, A., 2014. Business models for sustainable technologies: exploring business model evolution in the case of electric vehicles. *Res. Policy* 43, 284–300. <http://dx.doi.org/10.1016/j.respol.2013.10.014>.
- Bourgeois, L., Eisenhardt, K., 1988. Strategic decision processes in high velocity environments: four cases in the microcomputer industry. *Manage. Sci.* 34, 816–835.
- Budde, B., Alkemade, F., Weber, K.M., 2012. Expectations as a key to understanding actor strategies in the field of fuel cell and hydrogen vehicles. *Technol. Forecast. Soc. Change*, 79, 1072–1083. <http://dx.doi.org/10.1016/j.techfore.2011.12.012>.

- Busch, P., Jörgens, H., 2005. The international sources of policy convergence: explaining the spread of environmental policy innovations. *J. Eur. Public Policy* 12, 860–884. <http://dx.doi.org/10.1080/13501760500161514>.
- Carlsson, B., 2006. Internationalization of innovation systems: a survey of the literature. *Res. Policy* 35, 56–67.
- Cheah, L., Heywood, J., 2016. Meeting US passenger vehicle fuel economy standards in and beyond. *Energy Policy* 39 (2011), 454–466. <http://dx.doi.org/10.1016/j.enpol.2010.10.027>.
- Christensen, T., 2011. Modularised eco-innovation in the auto industry. *J. Clean. Prod.* 19, 212–220.
- Coenen, L., Bennenworth, P., Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. *Res. Policy* 41, 968–979.
- Connelly, M., 2003. Looking for help from Washington. *Automot. News* 77, 16 (*).
- Cowan, R., Hulten, S., 1996. Escaping lock-in: the case of the electric vehicle. *Technol. Forecast. Soc. Change* 53, 61–80.
- Dechezleprêtre, A., Neumayer, E., Perkins, R., 2014. Environmental regulation and the cross-border diffusion of new technology: evidence from automobile patents. *Res. Policy* <http://dx.doi.org/10.1016/j.respol.2014.07.017>.
- Diamond, D., 2009. The impact of government incentives for hybrid-electric vehicles: evidence from US states. *Energy Policy* 37, 972–983.
- Dijk, M., Yarime, M., 2010. The emergence of hybrid-electric cars: innovation path creation through co-evolution of supply and demand. *Technol. Forecast. Soc. Change* 77, 1371–1390.
- Dijk, M., Orsato, R., Kemp, R., 2013. The emergence of an electric mobility trajectory. *Energy Policy* 52, 135–145.
- Dyerson, R., Pilkington, A., 2005. Gales of creative destruction and the opportunistic incumbent: the case of electric vehicles in California. *Technol. Anal. Strateg. Manag.* 17, 391–408.
- EC, 2009. Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO₂ emissions from light-duty vehicles. *Off. J. Eur. Union* 52, 1–15.
- Frenken, K., Hekkert, M., Godfroij, P., 2004. R&D portfolios in environmentally friendly automotive propulsion: variety, competition and policy implications. *Technol. Forecast. Soc. Change* 71, 485–507.
- Gallagher, K.S., Muehlegger, E., 2011. Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology. *J. Environ. Econ. Manage.* 61, 1–15.
- Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Res. Policy* 31, 1257–1274.
- Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. *Res. Policy* 33, 897–920.
- Geels, F.W., 2006. Co-evolutionary and multi-level dynamics in transitions: the transformation of aviation systems and the shift from propeller to turbojet (1930–1970). *Technovation* 26, 999–1016.
- Gerard, D., Lave, L.B., 2005. Implementing technology-forcing policies: the 1970 Clean Air Act Amendments and the introduction of advanced automotive emissions controls in the United States. *Technol. Forecast. Soc. Change* 72, 761–778. <http://dx.doi.org/10.1016/j.techfore.2004.08.003>.
- Geels, F.W., Raven, R., 2006. Non-linearity and expectations in niche-development trajectories: ups and downs in Dutch biogas development (1973–2003). *Technol. Anal. Strateg. Manag.* 37–41.
- Harborne, P., Hendry, C., Brown, J., 2007. The development and diffusion of radical technological innovation: the role of bus demonstration projects in commercializing fuel cell technology. *Technol. Anal. Strateg. Manag.* 19, 167–188.
- Hekkert, M., Van den Hoed, R., 2004. Competing technologies and the struggle towards a new dominant design. *Greener Manag. Int.* 47, 29–44.
- Hovi, J., Skodvin, T., Andresen, S., 2003. The persistence of the Kyoto protocol: why other Annex I countries move on without the United States. *Glob. Environ. Polit.* 3, 1–23. <http://dx.doi.org/10.1162/152638003322757907>.
- Jewett, D., Truett, R., 2001. DCX's Oswald is dedicated to Durango hybrid. *Automot. News* 75, 26 (*).
- Kemp, R., Pontoglio, S., 2011. The innovation effects of environmental policy instruments – a typical case of the blind men and the elephant? *Ecol. Econ.* 72, 28–36. <http://dx.doi.org/10.1016/j.ecolecon.2011.09.014>.
- Köhler, J., Schade, W., Leduc, G., Wiesenthal, T., Schade, B., Espinoza, L.T., 2013. Leaving fossil fuels behind? An innovation system analysis of low carbon cars. *J. Clean. Prod.* 176–186 <http://dx.doi.org/10.1016/j.jclepro.2012.09.042>.
- Lau, L.C., Tan, K.T., Lee, K.T., Mohamed, A.R., 2009. A comparative study on the energy policies in Japan and Malaysia in fulfilling their nations' obligations towards the Kyoto Protocol. *Energy Policy* 37, 4771–4778. <http://dx.doi.org/10.1016/j.enpol.2009.06.034>.
- Langley, A., 1999. Strategies for theorizing from process data. *Acad. Manag. Rev.* 24, 691–710.
- Lee, J., Veloso, F.M., Hounshell, D.A., Rubin, E.S., 2010. Forcing technological change: a case of automobile emissions control technology development in the US. *Technovation* 30, 249–264. <http://dx.doi.org/10.1016/j.technovation.2009.12.003>.
- Lee, J., Veloso, F.M., Hounshell, D.A., 2011. Linking induced technological change, and environmental regulation: evidence from patenting in the U.S. auto industry. *Res. Policy* 40, 1240–1252. <http://dx.doi.org/10.1016/j.respol.2011.06.006>.
- Link, A., Scott, J., 2001. Public/private partnerships: stimulating competition in a dynamic market. *Int. J. Ind. Organ.* 19, 763–794.
- Magnusson, T., Berggren, C., 2011. Entering an era of ferment – radical vs incremental strategies in automotive power train development. *Technol. Anal. Strateg. Manag.* 23, 313–330.
- Mikler, J., 2005. Institutional reasons for the effect of environmental regulations: passenger car CO₂ emissions in the European Union, United States and Japan. *Glob. Soc.* 19, 409–444.
- Mikler, J.J., 2007. Varieties of capitalism and the auto industry's environmental initiatives: national institutional explanations for firms. *Motivations, Bus. Polit.* 9. <http://dx.doi.org/10.2202/1469-3569.1166>.
- Mikler, J., 2010. Apocalypse now or business as usual? Reducing the carbon emissions of the global car industry. *Cambridge J. Reg. Econ. Soc.* 3, 407–426. <http://dx.doi.org/10.1093/cjres/rsq022>.
- Moynihan, D., Shipan, C., Volden, C., 2012. Policy diffusion: seven lessons for scholars and practitioners. *Public Adm. Rev.* 72, 788–796.
- Nykqvist, B., Whitmarsh, L., 2008. A multi-level analysis of sustainable mobility transitions: niche development in the UK and Sweden. *Technol. Forecast. Soc. Change* 75, 1373–1387.
- Oltra, V., Saint Jean, M., 2009. Variety of technological trajectories in low emission vehicles (LEVs): a patent data analysis. *J. Clean. Prod.* 17, 201–213.
- Pilkington, A., 1998. The fit and misfit of technological capability: responses to vehicle emission regulation in the US. *Technol. Anal. Strateg. Manag.* 10, 211–224.
- Pilkington, A., Dyerson, R., 2006. Innovation in disruptive regulatory environments: a patent study of electric vehicle technology development. *Eur. J. Innov. Manag.* 9, 79–91.
- Pilkington, A., Dyerson, R., Tissier, O., 2002. The electric vehicle: patent data as indicators of technological development. *World Pat. Inf.* 24, 5–12.
- Pinkse, J., Kolk, A., 2012. Multinational enterprises and climate change: exploring institutional failures and embeddedness. *J. Int. Bus. Stud.* 43, 332–341. <http://dx.doi.org/10.1057/jibs.2011.56>.
- Pinkse, J., Bohnsack, R., Kolk, A., 2014. The role of public and private protection in disruptive innovation: the automotive industry and the emergence of low-emission vehicles. *J. Prod. Innov. Manag.* 31, 43–60. <http://dx.doi.org/10.1111/jpim.12079>.
- Pohl, H., Yarime, M., 2012. Integrating innovation system and management concepts: the development of electric and hybrid electric vehicles in Japan. *Technol. Forecast. Soc. Change* 79, 1431–1446. <http://dx.doi.org/10.1016/j.techfore.2012.04.012>.
- Porter, M.E., van der Linde, C., 1995. Toward a new conception of the environment–competitiveness relationship. *J. Econ. Perspect.* 9, 97–118.
- Rechtm, M., 2001. GM sues CARB over EVs. *Automot. News* 75, 1 (*).
- Reed, J., 2007. GM commits to selling hybrid car. *Financ. Times* 25 (*).
- Ross Morrow, W., Gallagher, K.S., Collantes, G., Lee, H., 2010. Analysis of policies to reduce oil consumption and greenhouse gas emissions from the US transportation sector. *Energy Policy* 38, 1305–1320.
- Schot, J., Geels, F.W., 2007. Niches in evolutionary theories of technical change. *J. Evol. Econ.* 17, 605–622.
- Schot, J., Hoogma, R., Elzen, B., 1994. Strategies for shifting technological systems. *Futures* 26, 1060–1076. [http://dx.doi.org/10.1016/0016-3287\(94\)90073-6](http://dx.doi.org/10.1016/0016-3287(94)90073-6).
- Shaheen, S., Wright, J., Sperling, D., 2002. California's zero emission vehicle mandate – linking clean fuel cars, car sharing, and station car strategies. *Transp. Res. Rec. J. Transp. Res. Board* 1791, 113–120.
- Sierczula, W., Bakker, S., Maat, K., Van Wee, B., 2014. The influence of financial incentives and other socio-economic factors on electric vehicle adoption. *Energy Policy* 68, 183–194. <http://dx.doi.org/10.1016/j.enpol.2014.01.043>.
- Stoffer, H., 2002. Unmoved by hydrogen, critics seek higher CAFE. *Automot. News* 76, 3 (*).
- Sushandoyo, D., Magnusson, T., 2012. A two-way relationship between multi-level technological change and organisational characteristics—cases involving the development of heavy hybrid buses. *Technovation* 32, 477–486. <http://dx.doi.org/10.1016/j.technovation.2012.05.002>.
- Sushandoyo, D., Magnusson, T., 2014. Strategic niche management from a business perspective: taking cleaner vehicle technologies from prototype to series production. *J. Clean. Prod.* 74, 17–26. <http://dx.doi.org/10.1016/j.jclepro.2014.02.059>.
- Truett, R., 2001. There's no escape from challenges for Bedi. *Automot. News* 75, 26 (*).
- Truett, R., 2009. Regulators help spur demand for green vehicles. *Automot. News* 84, 3 (*).
- Van Bree, B., Verbong, G., Kramer, G., 2010. A multi-level perspective on the introduction of hydrogen and battery-electric vehicles. *Technol. Forecast. Soc. Change* 77, 529–540.

- Van den Hoed, R., 2007. Sources of radical technological innovation: the emergence of fuel cell technology in the automotive industry. *J. Clean. Prod.* 15, 1014–1021.
- Wesseling, J.H., Faber, J., Hekkert, M.P., 2014. How competitive forces sustain electric vehicle development. *Technol. Forecast. Soc. Change.* 81, 154–164.
- Yin, R.K., 2009. *Case Study Research: Design and methods*. 2nd ed. Sage, Newbury Park, CA.
- Zapata, C., Nieuwenhuis, P., 2010a. Exploring innovation in the automotive industry: new technologies for cleaner cars. *J. Clean. Prod.* 18, 14–20.
- Zapata, C., Nieuwenhuis, P., 2010b. Exploring innovation in the automotive industry: new technologies for cleaner cars. *J. Clean. Prod.* 18, 14–20.
- Whitmarsh, L., 2012. How useful is the multi-level perspective for transport and sustainability research? *J. Transp. Geogr.* 24, 483–487.

René Bohnsack is assistant professor at the University of Amsterdam Business School, The Netherlands. His areas of research and teaching are in strategy and sustainability. His PhD thesis explores the role of car companies and governments in the evolution of low-emission vehicles. He has published in *Journal of Product Innovation Management* and *Research Policy*, and presented papers at several international conferences. Prior to starting his PhD project, he worked as a strategic controller for the GEA Group. For his studies, René attended the MLitt Programme for International Business at the University of St. Andrews, Scotland (with distinction).

Ans Kolk is full professor at the University of Amsterdam Business School, The Netherlands. Her areas are in corporate social responsibility and sustainability, especially in relation to international business firms and international policy.

She has published numerous articles in a range of international journals (e.g., *Journal of International Business Studies*, *Journal of Management Studies*, *Academy of Management Perspectives*, *International Marketing Review*, *California Management Review*, *Research Policy*, *Journal of Product Innovation Management*, *British Journal of Management*, *Journal of World Business*, *Organization*, *Harvard Business Review*, *World Development*) as well as book chapters and books. In 2009, she received the Aspen Institute Faculty Pioneer European Award (Lifetime Achievement Award) (<http://www.anskolk.nl; ankolk@uva.nl>).

Jonatan Pinkse is full professor at the University of Manchester, United Kingdom. His areas of research and teaching are strategy, innovation, sustainability, corporate social responsibility, and renewable energy. He has published papers in various international journals, including *Academy of Management Review*, *Journal of International Business Studies*, *Journal of Product Innovation Management*, *Research Policy*, *European Accounting Review*, *International Business Review*, *Management International Review*, *Business & Society*, *Business Strategy and the Environment*, and *European Management Journal*. He obtained his PhD at the University of Amsterdam with a thesis that was awarded with the 2006 O.N.E. Academy of Management Best Dissertation Award. In 2011, he received the Academy of Management O.N.E. Emerging Scholar Award.