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Closed-open innovation strategy for autonomous vehicle development

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Abstract: The automobile industry is faced with societal and market pressures to develop radically innovative cars for the future. The development of the autonomous vehicle (AV) is a strategic innovation in this area. This paper studies whether and how AV-innovation strategies at Tesla, BMW and Toyota are developed by using an open and/or closed innovation paradigm. More than ever, it appears that R&D departments of car manufacturers employ a combination of a closed and an open innovation strategy. In order to nurture their AV innovation strategy, they strategically decide which innovations to adopt from outside, and which parts of the R&D process to keep in-house. This paper presents and discusses the combined closed-open AV-innovation strategies used by three dominant car producers. It provides an insight in how they aim to gain a first-to-market position and sustainable competitive advantage in a new market segment of a highly saturated market.

Keywords: autonomous vehicles; AV; open innovation; R&D management; automotive industry.

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1 Introduction

Autonomous vehicles (AVs) are a key element in a smart urban mobility future. One important question for a smart urban mobility system is, how to combine technical challenges, related to for example seamless connectivity of the AV to its urban environment, with the necessary changes on the social dimension (Nikitas et al., 2017). Another key question is, in what manner the potential of the sharing economy can be fully realised for achieving economic, societal and environmental sustainability in future smart cities (Thomopoulos and Givoni, 2015). Technologically advanced, high tech AVs play a prominent role in the answers to these questions.

Large car manufacturers have lately been investing a lot of time, money and effort in research and development (R&D) for AVs. Several companies strive for a market share in AVs. This paper focuses on the use of closed and open innovation strategies by companies to create, develop and serve this market, and to become a leader in a future wherein smart urban mobility is a new standard. It analyses the wider impact of AVs, on R&D strategies of car manufacturers.

The comprehensiveness of these issues, related to how cities in the near future should be (re)designed based on IT possibilities, and the potentially huge role of the AVs fulfil in the smart urban mobility future, raises new challenges for the R&D processes of car manufacturers. Due to its dependence on seamless connectivity, as opposed to conventional cars, the AV requires an increased integration of software/information technology and hardware/physical technology. This distinguishing feature of the AV might confront car manufacturers with a lack of internal expertise and financial resources, and the need to make use of external expertise and external willingness to invest in such a radical innovation. In this context, it is reasonable to assume that open innovation as an R&D strategy plays an increasingly important role in AV development.

This paper aims to identify the characteristics of a possible shift from a closed innovation approach based on secrecy to a more open innovation approach based on disclosure within R&D departments of large car manufacturers involved in AV development. It examines how car manufacturers deal with the need for novel AV-expertise. It focuses on the extent to which open innovation is exercised as a leading paradigm in R&D, how it relates to the use of closed innovation practices, and in what manner automotive firms might benefit from a combined closed-open innovation strategy.

Open innovation means that valuable ideas can come from inside or outside the company and can go to market from inside or outside the company as well [Chesbrough, (2003), p.43]. Open innovation is a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology. It is opposed to closed innovation, whereby "firms that make new discoveries would think first about how to own and protect this knowledge, so that they could exclude rivals from this knowledge" [Chesbrough, (2003), p.172], for example by patenting, non-disclosure agreements and secrecy procedures. Closed innovation is in other words mostly about remaining in control of R&D processes.

The central question in this paper is:

> "To what extent is closed and open innovation used by and beneficial to car manufacturers in order to develop autonomous vehicles?"

This paper thus assesses to what extent firms in the automotive industry make use of closed and open innovation to put a radically new product – the AV – in the market, and to what benefit they employ closed and open innovation as guiding principles. It aims to clarify choices in terms of R&D strategy on a strategic level, by providing an analysis of the relative openness of R&D strategies of three automotive firms.

The paradigm of open innovation (Chesbrough, 2003) is used here to evaluate the relative openness of AV related R&D activities and to what extent openness and a mix of open- and closedness in innovation processes is beneficial for car manufacturing companies. This paper thus provides insight into how corporations behave during a technology race for which the final product (the AV) is assumed to have a potentially large market potential, especially in the context of smart urban mobility futures, but getting there requires big investments and taking considerable risks. It identifies a possible strategic shift in the automotive industry towards a more open innovation approach, as a result of the difficulty in the current market to gain a substantive competitive advantage, relative to other car manufacturers. This paper also shows the precariousness with which car manufacturers are confronted, of determining a balance in R&D strategies between closed- and openness.

This paper provides insights in the way in which an open and closed innovation approach can be combined by firms to innovate in the field of AVs. On an academic level, the research in this paper addresses a significant research gap because the current academic debate on open innovation emphasises the need for empirical data on the extent of openness employed in R&D strategies and the benefits this brings for the firm (Dahlander and Gann, 2010; Van de Vrande et al., 2009; Vanhaverbeke et al., 2012).

Furthermore, papers specifically focusing on open innovation in the car industry by Mondragon (2006), Ili et al. (2010), MacNeill and Bailey (2010), De Massis et al. (2012), Kamp and Bevis (2012), Karlsson and Sköld (2013) and Lazzarotti et al. (2013) addressed the relative lack of open innovation in the automotive industry. However, they also emphasised the need for open innovation as an R&D strategy to be adopted by car manufacturers in the near future.

Following this argument, this paper provides an assessment of and insight in the current state of the openness of R&D strategies in three firms in the car industry. On an industrial and more practical level, it assesses the current state of R&D strategies in the automotive industry by providing an insight in these strategies of three dominant car brands in the development of AVs.

The paper is structured as follows. First, the paper provides an overview of papers published on the paradigm of open innovation. The overview shows that one of the currently dominant issues raised with regard to the paradigm, is the extent to which open innovation is a beneficial R&D strategy for companies – as opposed to a strategy based on closed innovation. Then, the concept of closed versus open innovation is introduced and a conceptual framework is developed. After discussing the methodological choices that have been made and research methods that were used, three case studies are presented – on Tesla, BMW and Toyota. The case studies are analysed in the results section. Finally, the results of these analyses are discussed in the light of the research question and the literature review, leading to a concluding insight into the relative openness that is exercised while developing the AV, including the identification of a strategic shift in the researched cases. In the conclusion, the findings are discussed in the light of smart urban mobility systems.

2 Literature review and conceptual framework

2.1 Literature review

Open innovation as a new paradigm in the management literature was first introduced by Henry Chesbrough in 2003. Open innovation means that valuable ideas can come from inside or outside the company and can go to market from inside or outside the company as well. It quickly became highly popular to understand and organise R&D processes in firms reliant on innovative technology (Brunswicker and Chesbrough, 2018).

To categorise and bring order in the quickly growing literature on open innovation in the years that followed the introduction of the paradigm, Gassmann et al. (2010) distinguished several perspectives on open innovation; for example the spatial, structural and user perspective. They thereby acknowledge that other, earlier versions of the paradigm of open innovation, preceding the work of Chesbrough, can be found in the literature as well.

The spatial perspective on open innovation mainly analyses processes of innovation in the context of globalisation (Cohen and Levinthal, 1990). The structural perspective pays attention to the changing division in work, arising from adopting an inter-organisational strategy (Hagedoorn and Duysters, 2002). The user perspective is represented in the work of Von Hippel (1988), on how to involve users in innovation processes and incrementally develop user-inspired innovations. By focusing on the extent to which open innovation is beneficial for the car companies that are studied in this paper, via inbound and outbound processes of organising R&D, the perspective adopted in this research fits in the structural perspective on open innovation.

2.1.1 Open innovation as a relatively new paradigm

As open innovation remained a popular paradigm in the management literature, several other reviews of the publications on open innovation were published shortly after Gassmann et al.'s (2010) review (e.g., Huizingh, 2011; Spender et al., 2017; Hossein and Kauranen, 2016; Hossein et al., 2016). These more recent reviews point out some weaknesses in the theory on open innovation as well. One critique on open innovation developed in these reviews is that it is not a new paradigm, but actually addresses a phenomenon that is much older; in other words, it is to a certain degree 'old wine in a new bottle'. These authors argue that purely closed innovation does not exist; innovation has always been the result of a certain degree of openness.

This argument is supported by authors who preceded Chesbrough in researching the importance of openness in R&D management. Already in 1983, Mowery (1983) performed research on the way in which firms internally organise R&D and concluded that it was increasingly seen as providing a higher cost efficiency to companies, as opposed to outsourcing it. For many year firms adopted a closed innovation as the dominant strategy. As a response to Chesbrough's open innovation, Mowery (2009) argues approximately 25 years later, that closed innovation is losing ground, and open innovation practices become a new dominant standard way of conducting a firm's R&D.

Related to this point, it has been recognised by Huizingh (2011) and Bogers et al. (2016) that the paradigm of open innovation has an umbrella function by integrating earlier ideas on innovation and organisation. Examples of existing and established theoretical perspectives that can be seen as pillars on which the open innovation concept more or less is built (West and Bogers, 2017) are the perspectives of complementary assets (Teece, 1986) – whereby commercial success of a technological innovation is understood as a result of firm-specific assets, infrastructures and capabilities that optimally complement each other; user innovation (Von Hippel, 1986) – whereby innovation is understood mainly as a result of involvement of intermediate users instead of as a product from industries and manufacturers; exploitation-exploration (March, 1991; Tushman and O'Reilly, 1996) – whereby it is argued that successful commercialisation of a technology is the result of parallel processes of exploring and exploiting, i.e., combining R&D processes strategically and simultaneously with commercialisation practices; and absorptive capacity (Cohen and Levinthal, 1990), which is defined as a firm's ability to recognise the value of new information, assimilate it, and apply it to commercial ends. According to Huizingh (2011) this umbrella function of open innovation is an important reason for the success of open innovation. The question remains however to what extent the paradigm of open innovation really brings something new to the reservoir of theory and adds to the understanding of R&D practice.

2.1.2 Current debate: extent and benefits of open innovation

Also, it has been stipulated that there is a shortage of empirical evidence about the benefits of open innovation for companies, more specifically on how open innovation is improving the performance of R&D projects (Bahemia et al., 2017; Vanhaverbeke et al., 2012). Nonetheless, at least some research in this area has been conducted. Laursen and

Salter (2006) for example have investigated the benefits of open innovation for SMEs in the UK, based upon a large dataset. They follow Cohen and Levinthal (1990) who already argued some 15 years before the publication on open innovation by Chesbrough that the ability to use external knowledge is greatly beneficial to individual companies. Van de Vrande et al. (2009) have conducted a similar study on the benefits of open innovation for SMEs.

Some studies on the potential benefits of open innovation thus have been performed, but arguably not enough to provide conclusive evidence of the benefits of openness in innovation processes. Yet, existing research also stresses that open innovation practice is difficult to organise and to benefit from; it requires skills to balance existing and new activities in and by the firm, and challenges organisations (Lopez-Vega et al., 2017). Tapping into this discussion and based upon a literature review on the conceptual understanding of the importance of openness in innovation, Dahlander and Gann (2010) have argued that further research should therefore be focused on the extent and type of openness that matters for the course of the innovation process.

2.1.3 Research on open innovation in the automotive industry

Open innovation in the automotive industry specifically has been researched by Heneric et al. (2005), Mondragon (2006), Ili et al. (2010), MacNeill and Bailey (2010), De Massis et al. (2012), Kamp and Bevis (2012), Karlsson and Sköld (2013) and Lazzarotti et al. (2013).

Heneric et al. (2005) provide an in-depth overview of the European automotive industry, underpinned with detailed figures and statistics. Their research highlights the role of innovation and regulation in the car industry, as well as the increasing global character of the car industry.

Concerning open innovation, Mondragon et al. (2006) argue that competitive pressures in the automotive industry are forcing original equipment manufacturers (OEMs) to modify their traditional scope for value creation and value capture. This situation is exemplified by the semi-open architectures of today's motor vehicles, in the complete modification of hierarchies in the automotive value networks, and in the modification of the relations of automotive OEMs ecosystems.

Ili et al. (2010) argue that, around the time of publication of their paper, the paradigm of open innovation is hardly employed in the automotive industry. Their study does however recognise its potential value when the approach of open innovation would be adopted in the industry. Ili et al. (2010) conclude that employing open innovation as a research strategy can provide clues for car manufacturers on how to increase their innovative potential while at the same time controlling the costs of corresponding R&D processes.

MacNeill and Bailey (2010) argue that an open innovation approach can support the innovativeness and competitiveness of the automotive sector in a region, illustrating their argument by an empirical study of a UK region. Kamp and Bevis (2012) emphasise the importance of innovation support schemes run by public actors for automotive firms engaging in open innovation. Karlsson and Sköld (2013) conceptualise and refine the idea of open versus closed innovation by identifying vertical and horizontal relations in cooperation patterns. Lazzarotti et al. (2013) argue that firm specific goals as well as external factors might hamper the adoption of open innovation as an R&D strategy. They conclude that openness in innovation brings some advantages to the car manufacturers, but also that full benefits of open innovation can only be reaped when some barriers to fully adopt it as an R&D approach are removed; such as issues related to the management of intellectual property (IP).

Since 2006, open innovation is thus increasingly identified as an important component of the R&D strategy of automotive firms. As a possible explanation for this shift towards more open innovation, De Massis et al. (2012) importantly stress the point that the Western automotive market is saturated. They argue that, being first to market with an innovative car with relatively low R&D investments, is a key factor in attaining a sustainable competitive advantage in this market.

2.1.4 Contribution of this paper

This paper assesses to what extent firms in the automotive industry make use of open innovation, combined with closed innovation, to put a radically new product, the AV, in the market. It focuses on the extent to which they employ open innovation as a guiding principle and how they benefit from it. Thus it adds insight, firstly, into the extent of openness relatively adopted in their R&D strategies by the firms studied, and, secondly, to the benefits of open innovation adoption for these companies. It aims to clarify choices in terms of R&D practice on a strategic level by providing a fine-grained analysis of the relative openness of R&D strategies of three automotive firms and an assessment of the benefits of their adoption of a relatively open R&D strategy.

2.2 Conceptual framework: indicators for closed and open innovation

The theory on open innovation describes two contrasting models (open vs. closed). Open innovation implies that firms increasingly rely on external sources of innovation, by emphasising that ideas, resources and individuals flow in and out of organisations and therefore are not constrained by organisational boundaries.

As open and closed innovation projects progress over time, some of the projects are stopped because they are considered not feasible or in any way not fit the firm. In a funnel-like process, only a subset of the projects reach the development stage and few reach the market. In an open innovation project, the entrance of the funnel is open for projects of the organisation's R&D department as well as from outside firms, leading to a more collaborative, inter-organisational innovation process (Chesbrough, 2003).

Table 1 shows the contrasting principles of the two innovation models on six categories:

1. field of expertise
2. function of own R&D
3. attitude regarding research
4. market ambition
5. sources for ideas
6. IP.

The contrasting principles capture the essence of the different attitude each model has towards the innovation process.

Table 1 Contrasting principles of closed and open innovation

		Closed innovation	*Open innovation*
1	Field of expertise	The smart people in the field work for us.	Not all smart people work for us, so we must tap into the expertise of bright external individuals.
2	Functioning of own R&D unit	To profit from R&D, we must discover, develop and ship it ourselves.	External R&D can create significant value; internal R&D is needed to claim some portion of that value.
3	Attitude to research	If we discover it ourselves, we will get it to the market.	We do not have to originate the research in order to profit from it.
4	Market ambition	If we are the first to commercialise an innovation, we will win.	Building a better business model is better than getting to market first.
5	Sources for idea	If we create the most and best ideas in the industry, we will win.	If we make the best use of internal and external ideas, we will win.
6	Intellectual property	We should control our IP so that our competitors do not profit from our ideas.	We should profit from each other's IP when it advances our own business.

Source: Chesbrough (2003)

2.2.1 Inbound and outbound open innovation

Open innovation aims to maximise value creation in a landscape of abundant knowledge. Both inbound and outbound processes can be used. The inbound mode consists of many practices to explore and leverage external technologies and discoveries by a set of activities that is initiated by the firm itself. Firms for example organise product presentations through other firms, they take on orders, and they do reverse engineering; they occupy themselves with trend analysis and technology scouting; they build common R&D labs in which parties can cooperate; they make use of online portals and online market places for sharing potentially interesting ideas; and, they for example organise competitions and make use of venture capital (Chesbrough, 2003).

The outbound mode of open innovation involves the practice of developing external relationships to commercialise proprietary technologies (Bianchi et al., 2011). The central firm shares not only in terms of content of ideas, but also in terms of IP, knowledge, skills and employees. Open innovation for example is based on reciprocal license agreements, licensing, alliances and joint ventures. Patents are sometimes sold for strategic reasons. Knowledge, skills and personnel is shared through providing trainings for other R&D parties involved, provision of consultancy and exchanging personal.

A coupling of these inbound and outbound processes can also be in place. Several empirical studies suggest that companies prefer inbound over outbound activities (Huizingh, 2011). Explanations for this observation include the fear of diffusing relevant knowledge (Rivette and Kline, 2000) and giving away corporate 'crown jewels' (Kline, 2003).

2.2.2 Closed innovation

In the closed innovation model, research projects are launched from the science and technology base of a single, autonomously innovating organisation; in an innovation development process that is characterised by secrecy instead of openness. The following indicators for analytically identifying closed innovation practices are used in this study (Chesbrough, 2003):

a Field of expertise

The smart people in the field work for us. The R&D strategy of the company is determined by hiring the best and brightest people in the field and keep them in-house as long as possible.

b Functioning of R&D unit

To profit from R&D, we must discover, develop and ship it ourselves. Every step in the R&D process is taken in-house and on the basis of non-disclosure.

c Attitude to research

If we discover it ourselves, we will get it to the market. Commercialisation of the product is done by the company itself and alone, without others.

d Market ambition

If we are the first to commercialise an innovation, we will win a considerable share of the market. The competitive advantage gained is solely for the benefit of the firm itself.

e Sources for ideas

If we create the most and best ideas in the industry, we will win. Quantity and quality of the firm's own R&D is considered to be crucial in gaining a competitive advantage.

f IP

We should control our IP so that our competitors do not profit from our ideas. IP is strictly controlled by the firm itself. The firm keeps its cards to its chest.

2.2.3 Open innovation

The following indicators for analytically identifying open innovation practices are used in this study (Chesbrough, 2003):

a Field of expertise

Not all smart people work for us, so we must tap into the expertise of bright external individuals. Individuals are hired for a particular term and/or with a particular aim. When the project is done, the individual employee leaves. Or the firm does not hire the employee at all, but cooperates with another firm, based on agreements on how the benefits reaped in this way from the coupled R&D processes are shared among the firms involved.

b Functioning of R&D unit

External R&D can create significant value; internal R&D is needed to claim some portion of that value. Agreements on how the profit is shared amongst the parties involved are considered to be crucial for a well-functioning R&D unit.

c Attitude to research

We do not have to originate the research in order to profit from it. Original ideas are less important than the market share or competitive advantage, that the contribution to a shared R&D process brings.

d Market ambition

Building a better business model is better than getting to market first. Market shares and maximising a competitive advantage is what counts as the outcome of the R&D process, not originality of ideas.

e Sources for ideas

If we make the best use of internal and external ideas, we will win. A competitive advantage cannot be gained by working solo – in current markets firms can only maximise their profit by making use of the knowledge of other firms as well.

f IP

We should profit from each other's IP when it advances our own business. IP can be shared without damaging profits – it might even help in increasing profits and competitive advantage.

3 Methodology

Case study research is chosen as the basic method of research (Yin, 2003). This qualitative, in-depth research method provides the possibility for a detailed description and analysis of the adoption of the closed and open innovation approach in its actual empirical context. This research method enables the development of insights in an area that is relatively under researched - insights that are analytically valid for comparable cases in automotive and AV-development. With this research method a first insight can be developed which can serve as a proposition in further research aiming at development of a broader and deeper theoretical basis (Yin, 2003). The case study is performed by means of a documents study. The R&D processes around the three large car manufacturers are examined.

3.1 Selection of case studies

Currently both car manufacturers (e.g., Tesla) and I-tech companies (e.g., Google) are actively aiming for a significant share of the AV market, whereas such a share entails a significant competitive advantage in smart urban mobility futures. To focus the research, the R&D processes around three large car manufacturers are examined in a multiple case study research design. This research aims to identify a possible strategic shift within

R&D departments of car manufacturers. Therefore, I-tech companies fall outside of the scope of this research, which limits the external analytical validity of this research to comparable cases in which car manufacturers are involved.

The three focal firms are Tesla, BMW and Toyota. These car manufacturers are selected from a list of 33 corporations currently working on AVs (CBinsights, 2016). They are expected to be aligned along an axis from closed innovation to open innovation, respectively. This assumption is based on a preliminary research scan of several corporate websites. Furthermore, as summarised in Table 2, the three selected companies are not connected to each other by a parent organisation (as is common in the automotive industry), and all have their headquarters situated in countries on different continents; Tesla in the US, being seen as a prominent player in this field (e.g., Larminie and Lowry, 2012); BMW in Germany, having a long history as an innovative premium car manufacturer (e.g., Thomke, 2001); and Toyota from Japan, earning a strong reputation as a high-quality car builder (e.g., Womack et al., 1990). This adds to the diversity of the results and increases the analytical validity of conclusions for comparable cases (Yin, 2003).

Table 2 Facts and figures of the three focal firms

	Tesla	*BMW*	*Toyota*
Year of establishment	2003	1916	1937
Parent organisation	Tesla, Inc.	BMW Group/BMW AG	Toyota Motor Corporation
(Parent) headquarters location	Palo Alto, California, USA	Munich, Germany	Toyota City, Japan
(Parent) automotive employees (2016)	17,782	112,869	310,944
(Parent) automotive revenue* (2016)	\$6.8 billion	\$91.9 billion	\$229.1 billion

Note: *rounded to 1 decimal, by average 2016 exchange rates.

3.2 Data sources

In order to provide an understanding of the adoption of open innovation within each firm this multiple-case study design considers various publicly available documents as input data (see Appendix). The main data sources are the annual reports of the selected car manufacturers, over the period 2011–2016. Annual reports are considered a primary data source for studies on firm innovativeness with validity value (Michalisin, 2001). Annual reports communicate key information between a firm's management and its stakeholders, are a primary source of financial and operating information about the firm, and are subject to formalised, legally bound external control procedures. The annual reports provide a general view of the R&D processes within each firm. This view is expanded by additional information from corporate press releases, content from corporate and project websites, interview quotes by company officials and external research reports, in order to provide an understanding of the adoption of open innovation within each firm.

3.3 Data analysis

The gathered reports of the three selected firms are analysed by qualitative content analysis (Hsieh and Shannon, 2005). Open innovation and closed innovation principles are used as guiding concepts. Additionally, the described inbound and outbound processes have been used as indicators of closed and open innovation.

For each of the three examined car manufacturers, first an individual within-case analysis is made (Yin, 2003). This analysis provides a general view on the extent to which open innovation practices with respect to AV development are applied in each of the three selected firms. Thereafter, a cross-case analysis is performed (Yin, 2003). This results in a commentary on the adoption of the closed and open innovation paradigm with respect to AV development in the cases studied.

The within-case and cross-case analyses are guided and performed by means of describing and comparing the empirical situations for each case with regard to the theoretical elements as discussed in the theory section and summarised by Table 1 in this paper (Yin, 2003). Both the within-case and cross-case analyses concentrate on identifying patterns of open innovation, closed innovation and combinations of both in each case, i.e., within-case pattern identification and matching, and on identifying different patterns across cases, i.e. cross-case pattern differentiation (Yin, 2003).

4 Closed and open innovation practices

In this section, the results of the case study are presented for each of the three selected car manufacturers separately. Per firm, the results are divided into indicators for open innovation and indicators for closed innovation. The results section consists mainly out of quotes taken from the used data sources.

4.1 Tesla

Tesla's automated driving options include auto-steering, traffic aware cruise control, lane changing, automated parking and summon, and driver warning systems. In October 2014, Tesla began equipping all model S vehicles with hardware to allow for the incremental introduction of their Autopilot technology. In October 2016, Tesla started equipping all their vehicles with hardware needed for full self-driving capability, including cameras that provide 360 degree visibility, updated ultrasonic sensors for object detection, a forward-facing radar with enhanced processing, and a powerful new on-board computer (Tesla Annual Report 2016, p.5). However, the driver is ultimately responsible for controlling the vehicle (Tesla Annual Report 2016, p.5).

4.1.1 Field of expertise

Tesla claims that its roots in Silicon Valley enabled Tesla to recruit engineers with strong skills in electrical engineering, power electronics and software engineering (the latter increasingly important for AV development). They claim to hire the world's best and brightest people to help make this future a reality. Tesla competes for talented individuals with both mature and prosperous companies that have far greater financial resources than Tesla has, as well as with start-ups and emerging companies that promise short-term growth opportunities. As the firm puts it, their ability to combine expertise provides a broad capability in electric vehicle design and systems integration [Tesla Annual Report 2011, p.4, (2012), p.5, (2013), p.5]. Several annual reports show the worries of Tesla about not being able to hire individuals with sufficient expertise, since their products are high-performance vehicles, based on a different technology platform than traditional ones [Tesla Annual Report 2014, p.21, (2013), p.29, (2012), p.49, (2011), p.55].

4.1.2 Functioning of R&D unit

Although the focus of their argument is mainly on electric vehicle engineering, it suggests that for AV as a non-traditional technology, the car manufacturer also aims to have strong in-house expertise (Tesla Annual Report 2011, 2014, 2015, 2016). They state to design mostly in-house and to a lesser extent in conjunction with their suppliers [Tesla AR 2011, p.12, (2012), p.10, (2013), p.10, (2014), p.8, (2015), p.7, (2016), p.5].

The performance and safety systems of Tesla's vehicles require sophisticated control software. There are numerous processors in their vehicles to control these functions, and they write custom firmware for many of these processors. Drivers use the information and control systems in Tesla vehicles to optimise performance, customise vehicle behaviour. Tesla states that they develop almost all of this software, including most of the user interfaces, internally.[1]

4.1.3 Attitude to research

The company states that it designs their cars mostly in-house and to a lesser extent in conjunction with their suppliers [Tesla Annual Report 2011, p.12, (2012), p.10, (2013), p.10, (2014), p.8, (2015), p.7, (2016), p.5].

4.1.4 Market ambition

Tesla states that full autonomous driving is mainly a software problem and has set aggressive AV targets. Tesla believes that its strong in-house engineering and highly vertical manufacturing capacity will enable them to sustain their electric vehicle industry leadership (Tesla Annual Report 2013, p.5).

4.1.5 Sources for ideas

True autonomous driving will require far better electronic geographical maps than any map that currently exists. The company announced that the company starts to make high-precision digital maps based on sensor data collectively produced by its current car fleet. By using crowd-sourced data from its car owners, its' mapping service aims to adapt to changed conditions and provide highly accurate location-based information and directions to its vehicles. Within the organisation, Tesla has its own maps and navigation division responsible for the execution of this task.[1] However, about the data produced by this individual firm effort, the firm's CEO stated that the company "would be open to selling to other car companies or organisations that want to buy it."[1]

4.1.6 Intellectual property

In June 2014, Tesla's CEO announced a patent policy in which the company has pledged that they will not initiate a lawsuit against any party for infringing their patents through activity relating to electric vehicles or related equipment for so long as such party is acting in good faith. The car company claims to have made a pledge of opening up their patents for use by others in order to encourage the advancement of a common, rapidly evolving platform for electric vehicles, thereby benefiting themselves, other companies making electric vehicles, and in their view also the world.[2] The CEO said that other companies could 'just go ahead and use them' without any form of licensing process or discussion.[3]

The company has however continued to file for patents after taking their open source philosophy on IP.[4] It is unclear whether this attitude towards IP also applies to IP involving their Autopilot technology, as this technology could also be used in petroleum cars and therefore does not directly benefit the adoption of electric vehicles. Although this firm is pioneering in AV products, a study by Reuters (2016) shows that it does not own a large number of patents concerning AV, as the company does not appear in the top 26 companies with IP related to AV or automated driving. Concerning external IP, the company states that if their business is inhibited by IP of organisations or individuals, including their competitors, they may consider to seek a license from the holder of the infringed IP right [Tesla Annual Report 2014, p.71, (2015), p.24, (2016), p.28].

4.2 BMW

BMWs current automated driving options include an avoidance assistant, active cruise control, a crossing-traffic warning, a lane-change and lane control assistant with active side collision protection, which monitors the driving lanes next to the vehicle and supports the driver in the event of imminent collision with a corrective steering intervention. Also, BMW offers speed limit recognition and remote parking (BMW Annual Report 2016, p.52). The BMW iNEXT is scheduled to enter the market in 2021 and is claimed to be autonomously operating and highly connected (BMW Annual Report 2016, p.23). However, the driver was still ultimately responsible for controlling the vehicle (BMW Annual Report 2016, p.18).

4.2.1 Field of expertise

This car manufacturer is investing in ongoing collaboration. BMW is part of a joined research project aimed at the integration of vehicle, communication and traffic technologies into one system. The project, entitled '*Sichere Intelligente Mobilität – Testfeld Deutschland* (simTD)', involves numerous companies from the automotive and telecommunications industries, the government of the German state of Hessen and the city of Frankfurt am Main as well as various universities and scientific institutions. The simTD project is testing various driver assistance systems based on car-to-X communication methods. This includes communication with road infrastructure such as traffic lights, transfer of data describing the traffic situation and the condition of the road surface. This approach makes it possible to relay early warnings of accidents, traffic jams, emergency vehicles or the formation of black ice from one vehicle to other motorists in the vicinity. These advanced options represent highly innovative developments in autonomous driving. After four years of research work, the field trial commenced in October 2012 with over 120 vehicles. BMW is the only project partner taking part in the field trial with both cars and motorcycles.[5]

In August 2015, the firm also agreed with Nokia Corporation to acquire Nokia's maps and location-based services business (HERE Group), as part of a joint strategy to secure the long-term availability of HEREs products and services.[6] In 2016, it joined forces with

Intel and sensor specialist Mobileye to advance highly-automated and autonomous driving.[7]

4.2.2 Functioning of R&D unit

BMW states that, given the pace of technological change, collaboration in the field of R&D is customary in the automotive industry (BMW Annual Report 2016, p.51). The aim of its R&D activities, which may also include cross-sector cooperation, is to help find innovative solutions for individual mobility [BMW Annual Report 2015, p.38, (2016), p.51].

The company has since developed a scalable architecture that can be adopted by other automotive developers and carmakers to pursue state of the art designs and create differentiated brands. The offerings scale from individual key integrated modules to a complete end-to-end solution providing a wide range of differentiated consumer experiences. From an industry perspective, the company states that it is already seeing savings and speed in development, by sharing development costs and in pooling resources to develop a complete autonomous platform.

4.2.3 Attitude to research

BMW states that R&D is absolutely essential for the company to maintain a competitive advantage as a premium manufacturer (BMW Annual Report 2015, p.38). In 2014, the company claimed to aim for a leading position in both engineering and innovation (BMW Annual Report 2014, p.18), and that this innovation of their engineers and developers will ensure the company's continued success (BMW Annual Report 2014, p.17).

4.2.4 Market ambition

Besides taking a leading position, this company puts emphasis on being first to market and setting industry standards. Connectivity is one of the major trends in their industry. Vehicles, their drivers and their environment will be even more closely connected in smart urban mobility futures. The next logical step is increasing the extent of automated driving. At the company's headquarters, they state that they see themselves as both a driver and an innovator in this matter (BMW Annual Report 2015, p.17), and that the firm will without doubt continue to set standards in the field of connectivity on the roads (BMW Annual Report 2015, p.38). According to the company, new functions demonstrate its innovation leadership when it comes to the connectedness of the driver, the vehicle and the environment (BMW Annual Report 2012, p.34).

They welcome other companies – manufacturers, suppliers or technology companies – to participate and contribute to their autonomous platform. As part of this partnership, BMW will be responsible for driving control and dynamics, evaluation of overall functional safety including setting up a high performance simulation engine, overall component integration, production of prototypes and eventually scaling the platform via deployment partners.

4.2.5 Sources for ideas

Intel brings to BMW innovative high performance computing elements that span from the vehicle to the data centre. Mobileye contributes its proprietary high-performance computer vision processor responsible for processing and interpretation of input from the 360-degree surround view vision sensors as well as localisation. Intel and Mobileye have come to an agreement about the acquisition of Mobileye by Intel8.

4.2.6 Intellectual property

On the theme of IP, the company's financial statement shows under intangible assets that the company acquired licenses from external parties [BMW Annual Report 2014, p.126, (2013), p.53]. Their income statement does not specify whether the company also has revenue from license grants. According to Reuters (2016), the firm is not in a leading position concerning patents on autonomous driving or automated driving. The company has relatively little AV patents and an average number of automated driving patents compared to other companies in the given top 26. The car manufacturer states that the company puts high importance on protecting individual rights, business secrets, innovation and process information from unauthorised access, damage and/or misuse. It states that the protection of information and data are an integral component of their business processes [BMW Annual Report 2013, p.72, (2012), p.69].

4.3 Toyota

Toyota's current automated driving options include lane keeping assistance, a pre-collision system with brake-assistance, dynamic radar cruise control, dynamics integrated management for stabilisation of engine, steering mechanisms and brakes, a blind spot monitor and several parking assist functions. In spite of these functionalities, the driver is still ultimately responsible for controlling the vehicle (Toyota Annual Report 2016, p.29). In the end of 2017, Toyota installed a selection of these functionalities on nearly all models sold in Japan, the USA and Europe at an affordable price aimed at widespread adoption.

4.3.1 Field of expertise

Specified for autonomous driving, Toyota has R&D collaborations with three universities. Toyota has invested heavily in the establishment of joint research centres at both Massachusetts Institute of Technology (MIT) and the University of Stanford. Key program areas will be addressed by the two university campuses and Toyota, with combined research targeted at improving the ability of intelligent vehicle technologies to recognise objects around the vehicle in diverse environments, provides elevated judgment of surrounding conditions, and safely collaborates with vehicle occupants, other vehicles and pedestrians. The joint research will also look at applications of the same technology to human-interactive robotics and information service.[8]

Toyota established a third university partnership with the University of Michigan by financially boosting their research focused on artificial intelligence, robotics and autonomous driving. The funding for these academic partnerships was made available through the Toyota Research Institute (TRI), a wholly owned subsidiary of Toyota Motor North America focusing on enhancing vehicle safety and accelerating scientific discovery by applying techniques from artificial intelligence and machine learning.[9]

TRI also joined forces with 16 employees of Jaybridge Robotics, a company focusing on reliable automation of industrial vehicles.[10] Furthermore, TRI partnered with the Open

Source Robotics Foundation (OSRF) and its newly-formed for-profit subsidiary Open Source Robotics Corporation (OSRC) to expand the development of both open source and proprietary tools for Toyota's fast-growing robotics and automated vehicle research initiatives. This move to significantly expand TRIs research and engineering capabilities reflects Toyota's expansion beyond the boundaries of the conventional automotive industry to become a broad-based mobility technology company. TRI is also awarding OSRF a $1 million charitable contribution in support of its mission to advance the development and adoption of open source robotics software. TRI believes that the open source movement can catalyse the development of the robotics industry, and they state to be excited to help OSRF expand its impact.[11]

4.3.2 Functioning of R&D unit

The company actively seeks cooperation with other industries, especially with regard to the latest IT technology and the expanding data infrastructure [Toyota Annual Report 2011 (reg.), p.25]. It aims to make vehicle-infrastructure cooperative systems a reality as soon as possible, and works with government institutions to create standards for smart road infrastructure to upgrade the transportation environment. Toyota conducts field tests on public roads since 2006 in collaboration with government agencies and other private-sector companies (Toyota Annual Report 2014, p.19).

4.3.3 Attitude to research

Toyota states that the success of its R&D activities is a key element of the strategy (Toyota Annual Report 2013, p.45). To ensure efficient progress in R&D activities, the firm coordinates and integrates all phases, from basic research to forward-looking technology and product development. For the development of leading-edge components and systems the firm explicitly states the goal to stay ahead of competitors [Toyota Annual Report 2014 (reg.), p.34]. The company established a Research Institute to accelerate R&D of artificial intelligence technology (Toyota Annual Report 2016, p.90). This US based company plans to employ approximately 250 R&D employees.[12]

4.3.4 Market ambition

Toyota focuses on being first to market with their driving assistance technology. It completed in 1995 its first prototype advanced safety vehicle, the ASV-1. The ASV-2, which was introduced in 2000, incorporates emerging technologies, such as a safety support system that uses CCD stereo cameras to recognise obstacles in traffic lanes and an infrastructure-harmonised safety support system to warn the driver of pedestrian crossings. In 2003, this company became the first car manufacturer to implement a pre-collision system with a brake assist mechanism in its automobiles. In September 2006, the company established the world's first enhanced pre-collision system, which added functions to detect pedestrians in front, to support driver steering, and to react to vehicle collision. In February 2008, it developed the world's first driver monitoring pre-collision system, which monitors whether the driver's eyes are open, in addition to the face monitor, which monitors the direction the driver is facing (Toyota Annual Report 2014, p.91).

4.3.5 Sources for ideas

The firm's headquarters state that it is developing new system technologies and building platforms that leverage big data, such as a car's position, speed, and driving conditions, to create new value, enhance safety and improve quality. These systems combine highly accurate maps and navigation to support advanced driving with communication interfaces for controlling vehicles. The company created a system that is open to any company wishing to offer clients information, entertainment systems and content [Toyota Annual Report 2014 (reg.), p.21]. In order to develop a global platform, it announced a partnership with Microsoft and Salesforce.com to utilise cloud technology of these two companies in its internet and telematics [Toyota Annual Report 2014, p.28, (2015), p.27, (2016), p.28].

4.3.6 Intellectual property

Toyota puts significant emphasis on improving safety aspects of driving, also through IT solutions. The firm's Collaborative Safety Research Centre in the USA engages in joint projects with more than 16 universities and research institutions in North America. Their research results are open to the public and they are contributing to the US Government's policy planning [Toyota Annual Report 2014 (reg.), p.20].

On the theme of IP, the company wishes to contribute to sustainable mobility by promoting the spread of technologies with environmental and safety benefits. This is why it takes an open stance to patent licensing and grants licenses when appropriate terms are met [Toyota Annual Report 2016, p.91, (2015), p.88]. The firm's guiding IP principle is: greater corporate flexibility and maximising corporate value through the appropriate acquisition and utilisation of IP [Toyota Annual Report 2014 (reg.), p.35]. This is in line with findings by Reuters (2016), who identified the firm to be by far the number one company when considering the number of patents on autonomous driving technologies built up over the years. Its open stance to IP opens up possibilities for other firms to make use of this technology, although it is unclear to what extent this policy also applies to AV related IP.

5 Discussion

In this section, the results of the case studies are compared and contrasted with the closed and open innovation principles described in section two (see Table 1).

5.1 Extent of open innovation in the three cases

The results show three company-specific approaches to AV development, ranging from primarily closed innovation to fairly open innovation. Tesla initially made a claim with regard to the functioning of its R&D unit and attitude to research, that hinted towards an open innovation strategy. Nowadays, Tesla demonstrates that the closed innovation approach is still relevant and alive in these times. The company values their brand image as a technology pioneer and via their choice for a dominantly closed innovation, they implicitly claim the closed innovation approach fits its desired public appearance better.

BMW and Toyota show a more semi-open to fully open approach to AV development. Table 3 presents an overview of the principles of open and closed innovation, as found to be applied by each of the three examined car manufacturers.

Table 3 Overview of the principles of open and closed innovation

Principle		*Tesla*	*BMW*	*Toyota*
O1	Not all smart people work for us, so we must tap into the expertise of bright external individuals.		x	x
O2	External R&D can create significant value; internal R&D is needed to claim some portion of that value.	(x)	x	x
O3	We do not have to originate the research in order to profit from it.	(x)	x	x
O4	Building a better business model is better than getting to market first.			
O5	If we make the best use of internal and external ideas, we will win.		x	x
O6	We should profit from each other's IP when it advances our own business.	x	x	x
C1	The smart people in the field work for us.	x	x	
C2	To profit from R&D, we must discover, develop and ship it ourselves.	x		x
C3	If we discover it ourselves, we will get it to market.	x	x	
C4	If we are the first to commercialise an innovation, we will win.	x	x	x
C5	If we create the most and best ideas in the industry, we will win.			
C6	We should control our IP so that our competitors do not profit from our ideas.			
		( ) indicates former application		

5.1.1 Field of expertise

Considering the theme field of expertise, Tesla suggests that through its recruiting efforts and the company's roots in Silicon Valley, the firm has an inward focus on their workforce in line with closed innovation principles. BMW and Toyota also recruit their own employees for AV development, specifically from non-traditional automotive fields of expertise. However, these companies show more indicators of tapping into external expertise as well. Toyota explicitly states to evaluate their R&D projects in consultation with outside experts. These practices are in line with the open innovation philosophy on this theme.

5.1.2 Functioning of R&D unit

Notable results are obtained on the theme of functioning of the own R&D unit. At some point in time, all three firms applied the open innovation principle that external R&D can create significant value, while internal R&D is needed to claim some portion of that value. For Tesla, this is demonstrated through the integration of Mobileye's AV architecture in the early stage of Tesla's AV development. However, later on, Tesla shifted towards a more closed innovation approach, developing its own products for, for example, navigation of the AV.

BMW uses this architecture as well and is contributing to the newer versions. Many other car manufacturers also make use of Mobileye's architecture in their vehicles. Mobileye takes on a generating role while each carmaker takes on a specific commercialising role. Interesting is that Toyota is not listed as a Mobileye partner. Their co-innovation efforts seem to focus on public institutions and companies in the field of robotics.

5.1.3 Attitude to research

In the light of attitude to research, the results indicate that Tesla's focus on strong internal R&D capability leads to an innovation strategy of 'discovering it ourselves', which is a closed innovation principle. BMW and Toyota show a more open innovation approach by several joint research projects that the companies do not have to originate the research themselves to perceive the associated benefits. Examples of this are BMW's participation in the simTD project and Toyota's university partnerships. A similar reasoning applies to the theme of sources for ideas, of which Tesla's sources are mainly internal, while the other two car-manufacturers are more open to external input.

5.1.4 Market ambition

On the theme of market ambition, all three companies show signs of having a traditional view that getting to market first is an indicator of success. Tesla has set aggressive targets, which appear to be intended to communicate its image of technical superiority. BMW's claims of being a 'technological innovation frontrunner', being in 'leading position' and being 'first' and Toyota's multiple mentions of being 'first', demonstrate that all three companies apply a traditional, closed innovation approach on this theme focusing on being first-to-market as a focal firm.

5.1.5 Sources for ideas

Ideas are either internally developed by the company, or generated by external parties and used by the company. The differences in sources for ideas are especially notable in the way navigation data and IT is gathered and developed to make autonomous driving possible. Tesla uses crowd-sourced data from its car owners, offering to sell the data to any external party but basically developing their own navigational system. BMW draws their ideas from outside. They work together with Intel to acquire innovative high performance computing elements. Toyota plans to create a system that is open to any company wishing to offer clients information, entertainment systems and content, thereby working together with Microsoft.

5.1.6 Intellectual property

With respect to the last theme 'IP', there are no signs that a closed innovation approach is dominant. Tesla and Toyota appear to be open to both inbound and outbound licensing.

For BMW this cannot be concluded nor rejected, because this research is unable to identify outbound licensing activities. As mentioned before, the openness of the open innovation approach on this theme is questionable. A more modern open approach is demonstrated by the ‘good faith’ policy of Tesla, although this policy most likely will not apply to AV development.

5.1.7 Summary: Extent of closed and open innovation in the three cases

Tesla shows a primarily closed innovation model, with some open innovation aspects that were formerly adopted but are now largely abandoned (see Table 3). They for example prefer hiring people to work on the development of the AV instead of partly outsourcing this R&D. As a mainly closed innovator Tesla takes on both a generating and commercialising role. BMW shows a fairly open innovation model with a main focus on collaboration with commercial counterparts. They believe that getting another one’s idea to the market, when doing it themselves, might bring just as much benefit as bringing their own ideas to the market. Toyota also shows a fairly open innovation model, but this firm’s main open innovation focus is on collaboration with public parties. Toyota believes that external R&D can create significant value; internal R&D is needed to claim some portion of that value.

Being more open innovators, the car manufacturers BMW and Toyota focus mainly on the commercialising side, while outsourcing some of the generating tasks. An interesting similarity between the two more open cases – BMW and Toyota – is their involvement in a joint research project to initiate innovation at a system’s level. They thus recognise and acknowledge their role in designing a smart urban mobility future.

For all three cases a strong level of R&D capability is maintained and regarded as valuable. All cases put emphasis on being first to market. Overall, it appears that although all three AV car manufacturers, to a certain extent and at a certain point in time, adopted an open innovation approach, they all still use a considerable number of aspects of closed innovation in their innovation strategy.

As discussed in the literature review, Ili et al. (2010) argue that around the year of publication of their paper, open innovation as an R&D strategy is hardly employed in the automotive industry. Open innovation has however, they recognise, great potential value and could provide answers to the issue of how to continuously increase the innovative potential of the car industry, while at the same time control the costs of corresponding R&D processes.

In line with their argument, this paper substantiates that almost a decade later all three car manufacturers assume that adopting open innovation as an R&D strategy has the potential to maximise value from available knowledge - albeit that BMW and Toyota do so to a greater extent than Tesla. In the case of the AV, open innovation as an R&D strategy seems to be of great importance for car manufacturers. Technical challenges with regard to, for example, seamless connectivity and smart urban mobility, increase the need for car manufacturers to establish strategic alliances with parties that are developing the relevant supporting technologies.

5.2 Closed-open innovation strategy combinations for AV development

Strategic alliances are crucial in order to be able to radically innovate in a highly saturated market in which, without innovation, only marginal growth can be realised and decline of market share is a realistic threat. Investments in highly innovative products such as AVs, in order to create a new market segment with growth potential within, as well as apart from the saturated automotive market, is expensive and risky – especially since the successful adoption of the AV is partly dependent on broader changes in society and recognition of the need to design and implement smart urban mobility on a system's level (Nikitas et al., 2017).

The case studies support the proposition that open innovation approaches that facilitate strategic alliances, are needed to reduce the risk involved in investing in AV-related R&D, and increase the options to collaborate with partners who have complementary AV-related R&D. Thus, open innovation is increasingly recognised as being beneficial to the firm (Mondragon et al., 2006; De Massis et al., 2012; Kamp and Bevis, 2012; Karlsson and Sköld, 2013; Lazzarotti et al., 2013). This can be an explanation of why all three companies choose for a specific mixture between open and closed innovation as an R&D strategy. Further research needs to be conducted to gain a deeper analysis in the strategic choices of these firms, as this paper is based only on publicly available data on their R&D strategies.

Considering this limitation, it can tentatively be argued here that a first motivator of the firms studied to adopt a more open innovation R&D strategy is that their dispersion of R&D processes over other companies allows them to strategically spread the costs and risks involved. The firms do so by either choosing for a higher risk strategy to keep R&D mostly in-house, but also maximise potential profit – as Tesla does; or choosing for lowering the risks involved in attempts to be radically innovative by outsourcing R&D to other parties – as in the case of BMW and Toyota – but also accepting that potential profit will be less than in the case of Tesla as it needs to be shared with the other parties participating in the open innovation process. However, a first barrier to open innovation can be deducted from this argument as well, as closed innovation can be more beneficial in terms of short-term profit than open innovation, as revenues in the latter case need to be shared.

Looking at the specific nature of the AV in terms of technology, a second motivator can be identified. The characteristics of the technology and operational requirements force the firms to adopt open innovation in their R&D strategies. Communication across vehicles and communication across infrastructures is an important determinant for the success of the AV, as a key component of a smart urban mobility system. Thus, software and hardware compatibility actually force developers of IT for the AV to collaborate in order to minimise and control costs and ensure successful deployment of the AV.

Related to the development of the technologies for the AV itself, a second barrier to the adoption of open innovation as an R&D strategy can be identified. It may lead to the situation whereby firms miss the core competences to further develop the AV in the future, in case of successful adoption and implementation. The AV can be considered to be a radical innovation with a strong focus on seamless connectivity, further stressing the importance of co-innovating with outside partners (e.g., Karlsson and Sköld, 2013). It differs strongly from conventional cars. Firms thus basically start from scratch with reinventing the idea of a car.

Although it is argued that open innovation increases innovativeness and competitiveness of car manufacturers (MacNeill and Bailey, 2010), the three cases in this research indicate that this does not imply that closed innovation does not have worth with regard to innovativeness and competitiveness. Lazzarotti et al. (2013) argue that openness in innovation brings some advantages to the car manufacturers, but also that full benefits of open innovation can only be reaped when some barriers to fully adopt open innovation as an R&D approach are removed – such as issues related to the management of IP. Based on the case of Tesla, BMW and Toyota and the fact that they still, up to a certain extent, adopt a closed innovation approach, it can be stated that these barriers are still existent, and that, until they are solved, closed innovation remains a valuable approach to R&D as well.

To be fully and totally involved, using a more closed approach, may, in case of widespread adoption of the AV, on the longer term increase the competitive advantage of the firm – since core competencies in that situation are developed internally in the firm and can be used for further developing the first models. The firms are not dependent then on the continuation with the other firms involved in developing the first models. Open innovation thus also entails a risk for car manufacturers, while closed innovation still can be beneficial, especially in relation to maintaining the competitive advantage gained through it on the longer-term.

The question, to what extent open innovation needs to be adopted to maximise the benefits of open innovation of the company cannot however be answered by pointing out the 'right' balance between closed and openness. The answer to this question depends on the need to reduce costs and maximise profit on the short-term (e.g., Ili et al., 2010), in relation to the importance of gaining a competitive advantage in the market on the longer term (e.g., MacNeill and Bailey, 2010), as well as the technological requirements the AV specifically brings for successful adoption in itself. This shows the precariousness of finding the balance for firms in the automotive industry between an R&D strategy that is necessarily depending to a certain extent both on closed and open innovation indicators.

In the context of the debate on smart urban mobility systems, the successful development and eventual commercial breakthrough of the AV on the longer term is generally taken as a given. For the car manufacturers discussed here, the main question related to the organisation of their R&D processes is, how to optimally balance between closed and open innovation as an R&D strategy in order to optimise their market share in this upcoming AV market and in smart urban mobility systems – given their firm's philosophy, available expertise, financial resources, current market position and the general market situation, being the environment they operate in.

6 Conclusions

This paper considers R&D processes related to the development of the AV through a closed and open innovation perspective. It studies three large car manufacturers – Tesla, BMW and Toyota – and identifies a strategic shift within R&D departments of these firms from closed to a more open innovation.

The cases have shown joint research strategies, the use of technology architectures and a clear interest in research originated from outside of the company boundaries. For AV development, car manufacturers appear to have shifted to a certain extent towards a more commercialising role, while outsourcing part of the roles related to R&D.

Adding to the results of previous work on innovation in the automotive industry (e.g., Ili et al., 2010), whereby it is stated that the car industry does employ open innovation as an R&D strategy only in very limited way, open innovation practices appear to have increasingly been adopted. This provides evidence for the proposition that the push to be radically innovative, be first-to-market in the last eight years, and develop profitable business models for AVs has caused the car industry to be increasingly receptive to the potential benefits of an open innovation strategy. Yet, closed innovation has not been replaced by open innovation; all firms investigated use a mix of closed and open innovation.

Their strategy can be understood as an attempt to gain a competitive advantage in a highly saturated market, and/or in a completely new growth market for AVs related to the increased recognition of the need for smart urban mobility systems. Radical innovation in this area is an expensive and risky business, but can also deliver enormous revenues – especially since AVs play a very prominent role in these smart mobility systems. Spreading the risk via strategic alliances with parties providing the R&D that is needed for such radical innovation, via adopting, up to a differing degree, a more open innovation R&D strategy, can help firms in the car industry in being first to the AV-market, and/or developing profitable AV business models, and thus gain a considerable and sustainable competitive advantage.

The AV appears to be(come) a crucial component in realising a smart urban mobility future; a future in which smart cities will be characterised by transportation with lower carbon footprints and sharing habits and economies (Nikitas et al., 2017; Thomopoulos and Givoni, 2015). Dominant car manufacturers already invest in this future, and carefully seek for a balance between open and closed innovation R&D strategies in order to develop commercially viable versions of AVs that will shape this future. By walking this fine line, the car manufacturers hold a major key to a smart urban mobility future.

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Appendix

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Tesla	
Tesla Annual Report (SEC) 2011	http://ir.tesla.com/secfiling.cfm?filingID=1193125-12-81990&CIK=1318605
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Tesla Annual Report (SEC) 2014	http://ir.tesla.com/secfiling.cfm?filingID=1564590-15-1031&CIK=1318605
Tesla Annual Report (SEC) 2015	http://ir.tesla.com/secfiling.cfm?filingID=1564590-16-13195&CIK=1318605
Tesla Annual Report (SEC) 2016	http://ir.tesla.com/secfiling.cfm?filingID=1564590-17-3118&CIK=1318605
Tesla CEO on patents (audio, 13 January 2015)	https://www.techdirt.com/articles/20150217/06182930052/elon-musk-clarifies-that-teslas-patents-really-are-free-investor-absolutely-freaks-out.shtml
Tesla blog post on patents	https://www.tesla.com/BLOG/ALL-OUR-PATENT-Annual ReportE-BELONG-YOU
TEDtalk Tesla CEO (video, 28 April 2017)	https://blog.ted.com/what-will-the-future-look-like-elon-musk-speaks-at-ted2017/
Tesla Autopilot press conference (audio, 14 October 2015)	https://electrek.co/2015/10/14/tesla-reveals-all-the-details-of-its-autopilot-and-its-software-v7-0-slide-presentation-and-audio-conference/
BMW	
BMW Annual Report (regular) 2011	https://www.bmwgrou, p.com/content/dam/bmw-group-websites/bmwgroup_com/ir/downloads/en/2011/report2011.pdf
BMW Annual Report (regular) 2012	https://www.bmwgrou, p.com/content/dam/bmw-group-websites/bmwgroup_com/ir/downloads/en/2012/report2012.pdf
BMW Annual Report (regular) 2013	https://www.bmwgrou, p.com/content/dam/bmw-group-websites/bmwgroup_com/ir/downloads/en/2013/report2013.pdf
BMW Annual Report (regular) 2014	https://www.bmwgrou, p.com/content/dam/bmw-group-websites/bmwgroup_com/ir/downloads/en/2014/12507_GB_2014_en_Finanzbericht_Online.pdf

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Document studied	*Available via*
BMW	
BMW Annual Report (regular) 2015	https://www.bmwgroup.com/content/dam/bmw-group-websites/bmwgroup_com/ir/finanzberichte/pdf/en/12784_GB_2015_en_Finanzbericht.pdf
BMW Annual Report (regular) 2016	https://www.bmwgroup.com/content/dam/bmw-group-websites/bmwgroup_com/ir/downloads/en/2017/GB/13044_BMW_GB16_en_Finanzbericht.pdf
BMW, Audi and Daimler press release on HERE maps	https://www.press.bmwgroup.com/global/article/detail/T0228722EN/audi-ag-bmw-group-and-daimler-ag-agree-with-nokia-corporation-on-joint-acquisition-of-here-digital-mapping-business?language=en
BMW, Intel and Mobileye press release on AV	https://www.press.bmwgroup.com/global/article/attachment/T0266961EN/375103
simTD project partners	http://www.simtd.de/index.dhtml/enEN/Konsortium/Loesungspartner.html
Toyota	
Toyota Annual Report (SEC) 2011	http://www.toyota-global.com/pages/contents/investors/ir_library/sec/pdf/20-F_201103_final.pdf
Toyota Annual Report (regular) 2011	http://www.toyota-global.com/pages/contents/investors/ir_library/annual/pdf/2011/ar11_e.pdf
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Toyota Annual Report (SEC) 2013	http://www.toyota-global.com/pages/contents/investors/ir_library/sec/pdf/20-F_201303_final.pdf
Toyota Annual Report (SEC) 2014	http://www.toyota-global.com/pages/contents/investors/ir_library/sec/pdf/20-F_201403_final.pdf
Toyota Annual Report (regular) 2014	http://www.toyota-global.com/pages/contents/investors/ir_library/annual/pdf/2014/ar14_e.pdf
Toyota Annual Report (SEC) 2015	http://www.toyota-global.com/pages/contents/investors/ir_library/sec/pdf/20-F_201503_final.pdf
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Toyota, MIT and Stanford University Press release	https://newsroom.toyota.eu/toyota-establishes-collaborative-research-centers-with-mit-and-stanford-to-accelerate-artificial-intelligence-research/

Data sources (continued)

Document studied	*Available via*
Toyota	
Toyota and University of Michigan Press release	http://corporatenews.pressroom.toyota.com/releases/tri-university-michigan-accelerate-ai-research.htm
Toyota and Jaybridge Robotics Press release	https://newsroom.toyota.co.jp/en/detail/11351920
Toyota and OSRF Press release	http://corporatenews.pressroom.toyota.com/releases/toyota-research-institute-robotics-automated-vehicle-research-sept15.htm