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Autonomous Driving – a Challenge for the Automotive Industry

The automotive industry is one of the most important industries in Europe. This industry is responsible for 14% of total production and capital investment in the European manufacturing sector, and in Germany the share amounts to 22%. Structural change within this crucial sector is of relevance for the whole economy. Along with alternative propulsion systems such as electromobility, (semi-)autonomous vehicles are one of the big trends in the automotive industry. For established providers, the possibility of disruptive change poses a threat to existing markets, while a gradual introduction of new technologies also increases competition. Nevertheless, with their strong market position in the premium segment and especially their relevant research activities, European and especially German automotive manufacturers are well placed to successfully master the coming challenges in the automotive market.

Two fundamental technological developments currently have the potential to substantially transform the automobile market. The growth in "electric drive" technology and the digitalisation of vehicles call for new technologies and skills, while also opening up opportunities for new business models and providers. This may challenge and threaten the existing business models and fortunes of established manufacturers. Thus, this also has larger significance to the German, and therefore the European, economy. The development and economic significance of this market segment will be dependent on the legal framework that will be built around this new technology, which may permit or prohibit robotic vehicles, for example.

While the prospects for electromobility have already been discussed for many years,[1] there has been much less analysis of the disruptive potential of digitalised vehicles, a theme embedded in discussions of "Industry 4.0" and which could reach a climax in the emergence of the self-driving car. This paper aims to partially fill this gap, examining the major trends in relation to existing manufacturers and the position of suppliers competing for a share of the autonomous vehicles market.[2]

Autonomous vehicles

Autonomous driving takes a wide variety of forms. The classification produced by the Society of Automotive Engineers (Table 1) has attracted considerable attention.[3] The German Federal Highway Research Institute devised a similar taxonomy that differentiates vehicles driven solely by the driver (manual driving), driver-assisted, semi-automated, highly automated and fully automated.[4] The precise differences in the definitions are not discussed here in greater detail, but the decisive factor is the unanimous opinion that there is no clear-cut, binary distinction between automated and non-automated vehicles. Rather, both describe a continuum of progressive steps of automation.

Simply using a lane departure warning system, for example, is not considered automation. Lane departure assis-

1 See, for example E. Heymann, O. Koppel, T. Puls: Elektromobilität – Sinkende Kosten sind conditio sine qua non, in: Deutsche Bank Research, Aktuelle Themen No. 526, 2011, available at https://www.db.com/cr/de/docs/DB_Research_-_Elektromobilitaet_Sept._2011_(de).pdf; and E. Heymann, O. Koppel, T. Puls: Evolution statt Revolution – Die Zukunft der Elektromobilität, IW Analysen No. 84, Cologne Institute for Economic Research, 2012.

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2 This paper updates H. Bardt: Autonomes Fahren – Eine Herausforderung für die deutsche Autoindustrie, in: IW-Trends - Vierteljahresschrift zur empirischen Wirtschaftsforschung aus dem Institut der Deutschen Wirtschaft Köln, Vol. 43, No. 2, 2016, pp. 39-55; H. Bardt: Deutsche Autoindustrie und autonomes Fahren, in: Wirtschaftsdienst, Vol. 96, No. 10, 2016, pp. 776-778; and BASt – Bundesanstalt für Straßenwesen (Federal Highway Research Institute): Rechtsfolgen zunehmender Fahrzeugautomatisierung, in: Forschung kompakt No. 11/12, 2012, available at http://www.bast.de/DE/Publikationen/Foko/Downloads/2012-11.pdf?__blob=publicationFile.

3 SAE International – Society of Automotive Engineers: Automated Driving – Levels of Driving Automation are defined in New SAE International Standard J3016, 2014, available at http://www.sae.org/misc/pdfs/automated_driving.pdf.

4 BASt – Bundesanstalt für Straßenwesen, op. cit.

Table 1
Levels of driving automation

Level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving modes)
Human driver monitors the driving environment						
0	No automation	The full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver assistance	The *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial automation	The *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	System	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional automation	The *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a request to intervene	System	System	Human driver	Some driving modes
4	High automation	The *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a request to intervene	System	System	System	Some driving modes
5	Full automation	The full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	All driving modes

Source: SAE International.

tance systems go one step further and assume steering control. Autonomous driving on motorways is considered highly automated, while driver-independent driving in the city, e.g. robot taxis, is classed as fully automated.

This also means that the competition to develop (semi-) autonomous vehicle concepts does not start at the level of the self-driving car; rather, the competition has already started in the form of assistance systems that have already been developed and that are available in some vehicle classes on the market today. Established providers are already active in this area with their innovations. One large developmental step yet to be taken is the creation of a connected automated vehicle that communicates with separate external sensors; existing systems are only able to process information that the vehicle records itself.[5]

The different levels of automation are relevant to the various business models under discussion. The more complex the automated driving system is, the more deeply the automation technology must be integrated into other elements of the vehicle's systems. While assistance systems are already important competitive factors, and semi-autonomous systems are available on the market today, highly automated and fully automated vehicles are still a long way off. For a new market entrant, the development of self-driving cars could provide an opportunity to skip the initial stages of development or to handle these first stages as subcontractors for suppliers, thus disrupting the competitive environment.

Potential new providers

Functioning markets are characterised by the fact that (potential) newcomers can enter and transform them. To established providers, this potential competition drives efficiency and innovation, and the greater the threat the newcomer poses to existing market shares, the greater this drive becomes.

5 M. Klauda: Das Fahrzeug als Internet-Knoten: Chancen und Risiken für die Automobilindustrie; in: Verband der Automobilindustrie (VDA), 17th VDA Technical Congress Volume, Berlin 2015, pp. 131-158.

Newcomers and additional competitors can also enter existing markets with similar products, as has often been observed in the past. This is how car manufacturers from emerging countries have managed to increasingly push their way into the markets held by the triad (Europe, US and Japan). Some new entrants even took over traditional brands such as Volvo or Jaguar. In this case, there is a shift of market shares (or a redistribution of revenues generated in a growing market). However, new providers can also change the existing rules of a market, for example by introducing new technologies and business models. This creates a potential for disruptive change across the entire market - a change that could question the very foundations of established business models and thus pose a very serious threat to the success of established providers.

Autonomous vehicles could represent an opportunity for newcomers with high expertise in information technology to enter and disrupt the existing car market. A range of factors make this a favourable opportunity, one that also poses a particular challenge to established companies. The most important of these factors include:

- *Electromobility*: Facing the perspective of a further gradual rise in electromobility, the automotive industry is already in a state of flux. This trend challenges the value and differentiating potential of the existing core competencies of established automotive companies. New providers can attempt a successful market entry with new technologies, but existing manufacturers can of course also enhance their market position through new technological competence. The combination of technological advancements in electromobility and autonomous vehicle technology increases the chances of both successful market entry and repositioning, as from a customer's point of view, a completely new product can be offered which does not have to be directly comparable to traditional vehicles in every respect. The combination of both technologies increases the opportunities open to newcomers as well as the risk posed to established companies.

- *Digital network competence*: Companies such as Apple or Google have considerable expertise in the development of digital products and applications, as well as in networking subsystems, vehicles and infrastructures. Applying this competence to automotive applications can create a significant edge in terms of expertise in digital networking and autonomous driving, provided the necessary vehicle-related competencies can be brought in from suppliers or manufacturers.

- *Data competence*: The ability to handle large amounts of data enables new digital business models, and this is also a form of competence that is well advanced in digital-based technology companies. The generation and use of large data sets (big data) holds much potential for entrepreneurs to develop new, as yet undiscovered business models based around individual mobility. Experience in the commercial use of big data, such as in online advertising, opens up competitive opportunities for existing internet-based companies in the context of autonomous vehicles.

- *Capital strength*: Google (or, more specifically, Alphabet) and Apple are the two companies in this sector with the highest stock market valuations worldwide. Uber, a very new company, has also earned a high market valuation. This shows not only investors' positive expectations, but also a significant investment potential for these companies. For example, it has been reported that Apple was in discussions to buy McLaren, a British producer of sports cars, which illustrates that these companies have the financial means to overcome barriers to entering new markets, even the automotive sector.

- *Disruptive experience*: Unlike traditional large automotive manufacturers, companies like Google, Apple or Uber have strong experience in disruptive business models. With the launch of the iPod and iPhone, Apple not only developed the market for mobile internet, but it also completely revolutionised business models in the music industry through the success of its digital music download service. Meanwhile, Google AdSense turned the advertising market on its head and severely jeopardised the business models of newspaper advertising providers in the process. Uber, more controversially, challenged the business structures of the taxi trade across the globe. Thinking in terms of fundamental alternatives that go far beyond the existing business models in the market has been a key component of the success of these companies. It is true that past disruptive experiences do not necessarily mean that similar efforts will succeed in the future. That said, however, there is at least entrepreneurial and cultural potential there that can support these companies in transforming the automotive market, too, with disruptive innovations. At the same time, any such restructuring or adaptation to far-reaching changes can be expected to pose a greater challenge to existing players.

Attractive automotive market

The international market for automobiles is already highly competitive. Numerous companies compete for customers across different segments (size, class and qualities). Despite diverse national technical regulations, the big

names have a global presence. In addition to the traditional European and American manufacturers, Japanese, Korean and Chinese providers have pushed their way into the market in recent decades. The growth in electric drive technology has also led to the entry of new challengers such as Tesla into the market.

Despite the strong level of competition present in the automotive sector, this market can still be attractive to new players. This applies both to companies that focus on classic products, for example the Chinese providers currently entering international markets, as well as to companies from other industries. These new market entrants play a particularly significant role when they alter the traditional parameters of competition or transform these through new technologies and business models. There are a number of possible reasons for the attractiveness of the automotive market for technology companies from outside the industry:

- *Willingness to pay*: Electronic special features purchased with the vehicle can be much more expensive than alternatives that are not integrated into the vehicle itself. For example, an external satellite navigation system can generally be acquired for a fraction of the cost of a fitted device added through the special features list (and therefore better integrated into the vehicle). This phenomenon was seen in car radios long before the rise in connected vehicles. Even if consumers benefit from features being integrated into the vehicles as features rather than add-ons, high-margin products in this segment benefit from technophile customers' high willingness to pay. This makes the entire spectrum of electronic components, whether related to entertainment, connectivity or (semi-)automation, an interesting option for providers of such products. Even driving-related features provide an attractive profit opportunity for providers. The added comfort and security offered by automated driving creates market and revenue potential for manufacturers.[6] This means new providers could participate in the automotive market without needing to offer a vehicle of their own.

- *Technology*: As far as the development of digital components in the areas of networking and entertainment is concerned, manufacturers of relevant non-automotive technologies have a considerable advantage in terms of expertise. One area where this applies is designing, programming and updating apps. Companies from outside industries also have a technological lead on automotive manufacturers in other areas, such as the development of future core components, e.g. batteries. This technological lead represents a benefit to customers that can be easily identified and visualised and therefore provides a great opportunity for suitable technology companies to enter the automotive applications market.

- *Shift in creation of value added*: A change in requirements for cars can lead to a change in differentiating factors. Thus, it is conceivable that it will not so much be the engine but the digital connectivity and autonomous systems used that differentiate brands from one another and play a strong role in purchasing decisions. Such a situation could move the focus of value creation away from classic elements of vehicle manufacturing and towards the use of additional modern technologies, where technology companies can use their competitive advantage to distinguish themselves from traditional manufacturers. In essence, it is about whether automotive manufacturers purchase electronic components or whether digital technology companies purchase vehicles. The possibility of shifting the differentiating factors and centre of value creation has major disruptive potential, and therefore also represents great opportunities for new entrants and threats to established providers.

- *New business models*: The value creation shift is even more prominent in new business models that challenge the notion of ownership and established differentiators while potentially making cars an accessible commodity. This would be possible if a company like Uber were to organise a robot taxi service using fully automated self-driving cars. Carsharing services from various automotive manufacturers are also moving in this direction.

- *Data*: Data generated during vehicle operation can also be collected, analysed and applied to improve technological components and develop new business models based on big data. Internet companies already have a lot of experience here and are therefore well situated to successfully exploit the opportunities offered by vehicle-based data.

In contrast to the opportunities that lie in fundamental changes to market conditions, the classic elements of the automotive market seem less interesting for electronics and internet companies. The construction of car bodies, decentralised distribution, maintenance, repairs and supply of spare parts are far removed from the existing competencies of these potential new entrants. On the other

6 C. Grote: Automatisiertes Fahren – Quo Vadis? Entwicklungen und Herausforderungen aus Herstellersicht, in: Verband der Automobilindustrie (VDA), 17th VDA Technical Congress Volume, Berlin 2015, pp. 193-208.

hand, these competencies can be acquired by buying existing car producers. The potentially disruptive changes in technology and business models pose a great challenge to established automotive manufacturers.

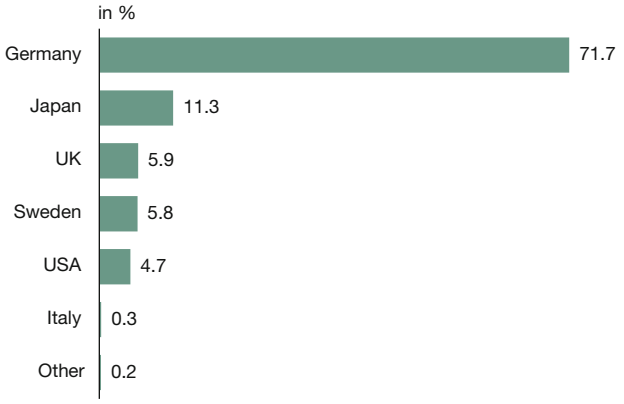
Position of international manufacturers within the automotive industry

As the automotive industry is based on cooperation among different manufacturers and various suppliers of parts and specific technologies or services, complex international value chains have been developed. The cooperation of manufacturers and suppliers is important for innovation within the industry. Most of the suppliers work with several if not all major manufacturers. New technologies developed by first or second-tier suppliers will not be used by specific brands exclusively for a long period of time. Technologies can spread quickly from one car brand to another.

The frequently observed and thoroughly traditional innovation process in the highly innovative automotive industry can typically be represented as follows.[7] Innovative technologies are usually first offered in luxury and premium class vehicles. Customers' willingness to pay in this segment is comparatively high, which creates sufficient incentives to innovate. At the same time, customers purchasing luxury and premium class vehicles demand interesting new features with each new purchase. Only with the course of time do these innovations become standard and available in the mass-market segment. This gives luxury and premium vehicles an important function in the manufacture and adoption of innovations in the automotive market. Meanwhile, premium providers must ensure they are seen as especially innovative.

In regards to their existing portfolios, German manufacturers have a good starting position for competing in autonomous vehicles – at least in comparison with other vehicle manufacturers. The large share of the premium segment in vehicle production ensures that there is a high level of innovation. Customers buying luxury and premium vehicles may also have an associated willingness to invest in assistance systems and semi-autonomous and autonomous driving systems. The mass market segments also make it possible to subsequently apply these technologies to create additional revenue. The combination of strong, independent brands in the premium and mass market segments is a unique feature of the German automotive industry and also provides a competitive advantage in the development of autonomous vehicles. Other European and Japanese companies have much lower shares of premium products in their portfolios.

Figure 1
Share of the global premium-level automotive market by country of origin, 2013



Note: Sample of 66 companies.

Source: F. Dudenhöffer: Lassen sich „Hochkosten"-Standorte durch Premiumbranchen absichern? Erfahrungen aus der Automobilindustrie, in: ifo-Schnelldienst, Vol. 67, No. 6, 2014, pp. 26-30; own calculations.

German manufacturers together make up almost 72% of the premium segment of the global car market (Figure 1). Japan is in second place with a respectable 11%. The UK, Sweden and the United States each come in at just five to six per cent. (Semi-)autonomous systems will at first primarily be found in premium products and then diffuse into the mass market, generating economies of scale. Conversely, a particular innovation in vehicle automation could offer an opportunity for companies that have thus far been less successful at establishing themselves in the premium segment – however, the high investments required do pose an obstacle. The German industry's strong established position in a market environment undergoing transformation therefore comes with the risk that its position will be increasingly undermined.

Innovation in autonomous driving

The automotive industry is generally considered to be highly innovative, and the competition to develop the autonomous vehicle is essentially a competition of innovation.[8] The potential entry of entirely new competitors has significantly increased the competitive pressure and the associated potential for technical innovation. Through the analysis of patent registrations since 2010, this can be mapped in order to show current innovation activity.

7 ZEW – Zentrum für Europäische Wirtschaftsforschung: Innovationsverhalten der deutschen Wirtschaft – Indikatorenbericht zur Innovationserhebung 2015, 2016, available at http://ftp.zew.de/pub/zew-docs/mip/15/mip_2015.pdf.

8 Ibid.

In addition, patents connected to autonomous driving, originating from 66 companies in four groups, have been identified using the World Intellectual Property Organisation's PATENTSCOPE database. This was done through the use of a combination of terms to search the patent documents and categories in the international patent classification system. The results were consolidated into groups and countries, whereby some joint registrations were filtered out. However, it is not possible to completely rule out some double registrations. Likewise, the quality of patents and closeness to concrete applications in cars could not be clearly differentiated. The companies include 23 international automotive providers, 21 large suppliers, 15 international electronics companies, and seven challengers such as Apple, Google and Tesla. The companies in this sample are responsible for more than 61% of all relevant patents found in the PATENTSCOPE database.

In total, 4,665 patents relating to autonomous driving were found in our sample of 66 companies (Table 2). Of these, more than half can be attributed to classic automotive manufacturers, while supplier companies filed a good third of them. The challengers are responsible for just over six per cent of the patents. Even if this figure may be underestimated, these companies still ought to have applied for a larger proportion of patents for their innovations, as this number is quite small; moreover, it is strongly concentrated on Google.

German companies appear to be much more active in their pursuit of innovation. Indeed, 55% of patents relating to autonomous driving registered worldwide are attributable to German manufacturers, with a total of 59% attributable to EU manufacturers. The United States and Japan are the two other significant countries for innovation in this area. None of the challenger companies come from Europe. However, among established automotive manufacturers, a good 50% of patents worldwide are attributable to European and German providers in particular. The strength of the premium segment in the industry plays an important role here. This is where manufacturers and suppliers form an important innovation network in an environment of structural change.[9] However, the integration of value chains and the cooperation of suppliers with several manufacturers can spread autonomous driving innovation quickly and will make long-term advantages improbable.

The international character of value chains in the automotive industry makes it necessary to differentiate between

Table 2
Patents issued for autonomous driving, 2010-2016

	World-wide	EU	Share of EU (%)	Germany	Share of Germany (%)
Automotive manufacturers	2,617	1,312	50.1	1,288	49.2
Suppliers	1,593	1,420	89.1	1,243	78.0
Electronics	167	48	28.7	42	25.1
Challengers	302	0	0.0	0	0.0
Total	4,665	2,770	59.4	2,567	55.0

Note: Sample of 66 companies.

Sources: PATENTSCOPE; IW calculations.

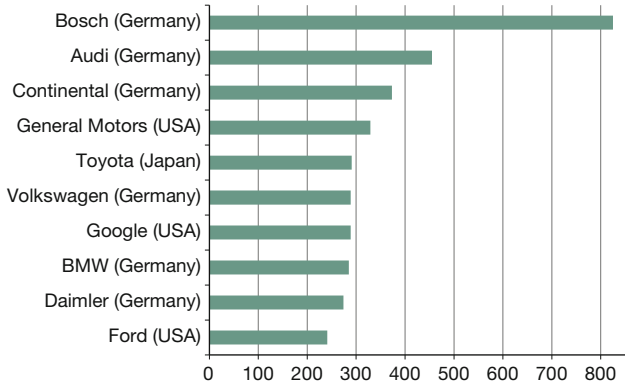
the "home country" of a company and the actual country of production, value added and employment. Although German manufacturers and suppliers have a strong position in the development of autonomous cars, production will take place not only within Germany but also in many other countries around the world. German manufacturers have important production capacities in Central and Eastern Europe, the United States, Mexico, China and other countries. Suppliers have built up production close to the manufacturers. Japanese companies produce cars in North America and the United Kingdom. American companies also have production plants in Germany. Autonomous cars will be produced in most of these countries. The necessary electronic equipment and software, however, can be shipped at much cheaper rates. Therefore, production of these components may be more concentrated in the future. As these parts and software are probably very value added intensive, traditional host countries for car production could lose value added, even if production stays within the country.

A look at the top ten companies registering patents in autonomous driving also highlights the significance of German firms, of which there are six among the top ten – four manufacturers and two suppliers (Figure 2). Google stands out among the challengers, landing in fifth place among all companies. Given the company's background in technological innovation, this shows Google to be a competitor that should be taken very seriously. The combination of technical and non-technical expertise in data-based business models and disruptive processes is what leads to the expected strength of Google in the competition to develop the cars of the future. Exclusive cooperation between Google and a single large car manufacturer could lead to a long-term advantage in the market, as this would limit the potential for the quick distribution of these new technologies to other companies.

In addition to the distribution of patents among companies, the overall development of patent applications is in-

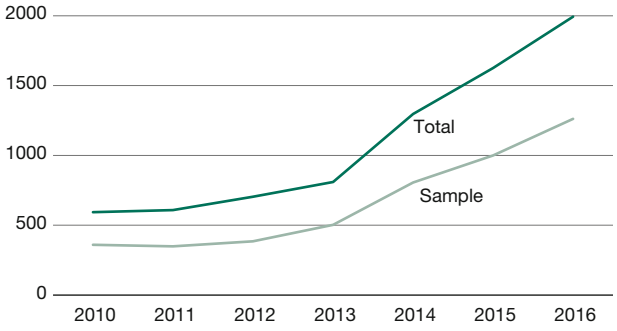
9 IW Consult, Cologne Institute for Economic Research: Zukunft der Automobilindustrie – Was bringt der Strukturwandel für die Automobilzulieferer?, Cologne 2011.

Figure 2
Top applicants for patents in autonomous driving, 2010-16



Sources: PATENTSCOPE; IW calculations.

Figure 3
Patents issued for autonomous driving, 2010-16



Note: Sample of 66 companies and total patents based on annual data.

Sources: PATENTSCOPE; IW calculations.

teresting. The number of patents filed has increased from about 600 in 2010 and 2011 to nearly 2000 in 2016 (Figure 3). About 350 were filed by the companies in this sample in both 2010 and 2011, while they were responsible for nearly 1300 patents last year. This demonstrates the increasing relevance of autonomous driving technologies for the industry.

Conclusion

The automotive industry is one of the strongest pillars of the manufacturing sector. 13% of the sector's turnover, production and investment is attributed to the automotive industry in Europe, while in Germany this figure is 22%. Significant risks for the development of this industry would affect the whole economy, and thus structural changes are of political relevance. The development of autonomous cars involves considerable disruptive potential for the global automotive industry. New providers may enter the market if they are able to combine technological advantage with expertise in vehicle construction, which can also be brought in by traditional manufacturers and suppliers in particular. Expertise in the development of new data-based business models and company cultures that are capable of dealing with disruptive situations offer great opportunities for newcomers like Google, which poses a significant challenge to established companies.

Development thus far has been marked by gradual technical progress, which has been strongly influenced by established manufacturers and suppliers. Judging by the numbers of registered patents, German companies are clear leaders worldwide. For future success, access to technologies that make vehicles stand out in the market will be crucial, as this is what will determine where value is created in this industry.

However, this comparatively comfortable situation for the German automotive industry does not mean it can rest on its laurels. Progress here will be accelerated by pressure from challengers such as Google, which has significantly increased competition through its general innovation and specific patent applications in the development of autonomous driving. The key entrepreneurial challenges lie in both further technical development and establishing completely new and data-based business models.

The automotive industry is of central importance to the economies of Europe, especially Germany, and it is correspondingly important to Europe's automotive industry that the opportunities offered by new technological developments are properly exploited. To make this possible, the following policies are required at a European level:

- The licensing and liability laws for autonomous vehicles must be standardised across the European Union.
- Technical specifications must be identical across the major economies worldwide. If negotiations on the Transatlantic Trade and Investment Partnership are resumed, they should be used as an opportunity to develop a common regulatory framework.
- The digital infrastructure to allow communication between different vehicles and between vehicles and infrastructure must be expanded rapidly.
- Data protection regulations must be designed in a way that ensures drivers' privacy is protected without unduly restricting the development of new technical opportunities and innovative business models.