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# HOW THE GREEN AND DIGITAL TRANSITIONS ARE RESHAPING THE AUTOMOTIVE ECOSYSTEM

OECD SCIENCE, TECHNOLOGY AND INDUSTRY
**POLICY PAPERS**
March 2023 **No. 144**

OECD
BETTER POLICIES FOR BETTER LIVES

# OECD Science, Technology and Industry Policy Papers

This paper was approved and declassified by written procedure by the Committee for Industry, Innovation and Entrepreneurship (CIIE) on 9 December 2022 and prepared for publication by the OECD Secretariat.

*Note to Delegations:*

*This document is also available on O.N.E. under the reference code*

*DSTI/CIIE(2022)11/FINAL*



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# How the green and digital transitions are reshaping the automotive ecosystem

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The automotive sector is important across OECD countries in terms of value-added and R&D, but is also heavily affected by the green and the digital transformations. This paper offers a novel and holistic view of the automotive sector and its surrounding ecosystem based on a combination of Inter-Country Input-Output (ICIO) tables, patent data, mergers and acquisitions (M&A) transactions, cross-country micro-distributed data and firm-level balance sheet data. It identifies the boundaries of this industrial ecosystem including connected sectors (e.g. upstream and downstream) as well as knowledge and technology providers (e.g. universities or the digital industry). The paper documents emerging trends at the geographical and technological levels and provides a comprehensive assessment of the ecosystem's changing microstructure, with a growing role of young and digital-intensive companies. Finally, it provides recommendations for effective public policies to support the automotive ecosystem, with a focus on innovation, competition and the growth of young firms.

**JEL codes:** L62 / O25 / L50 / O38 / Q58

**Keywords:** Industrial ecosystems; Automotive; Decarbonisation; Industrial policy; Autonomous vehicles

# Executive summary

The automotive sector is of utmost importance across OECD countries in terms of value-added and R&D (11% of business R&D expenditures on average across OECD countries in 2018). It also induces, more than many other sectors, a number of upstream and downstream jobs and significantly contributes to exports.

Car manufacturers are at the core of a broader industrial ecosystem, which includes suppliers and downstream sectors, related sectors also facing challenges linked to decarbonisation of mobility and sharing some of their technologies, and more generally skills, knowledge and framework conditions (including universities, research institutes and labour market institutions).

Nowadays, this industrial ecosystem is one of the most salient examples of an industry simultaneously affected by the green and the digital transformations, which are profoundly changing technologies (connected, autonomous, shared, electric (CASE) vehicles) and business models. Despite massive support by governments, the crisis has caused severe output losses in the ecosystem and revealed the dependency to crucial input such as semiconductors.

Building on a unique combination of data sources, including Inter-Country Input-Output (ICIO) tables, patent data, mergers and acquisitions (M&A) transactions, cross-country data from the microdistributed projects Dynemp and Multiprod, and firm-level data, this paper identifies the boundaries of the industrial ecosystem surrounding the automotive sector and offers a comprehensive assessment of its changing microstructure and emerging trends.

Based on these data sources, this paper defines the automotive ecosystem as a set of 14 sectors having strong linkages with the automotive industry. The composition of the ecosystem reflects a variety of linkages: upstream sectors providing inputs to the automotive sector (e.g. fabricated metal products, rubber and plastic products), downstream sectors (e.g. wholesale and retail trade and repair of motor vehicles), sectors heavily relying on motor vehicles as a capital good (e.g. land transport, rental and leasing activities), sectors providing capital goods to the automotive sector (e.g. machinery and equipment), sectors sharing the same technologies or challenges (e.g. other transport equipment) and sectors developing core technologies (e.g. electrical equipment and ICT sectors). However, as a conceptual framework to define industrial ecosystems and their boundaries is lacking, this definition, even if based on analytical results, partly rests on arbitrary choices. Besides the sectors included in the ecosystem, the automotive sector relies, as many other sectors, on a wide range of ancillary business services (professional, scientific and technical activities, administrative and support services, financial and insurance services).

Beyond the identification of sectors related to the ecosystem, the analysis also underlines several messages regarding the changing microstructure of the ecosystem.

- While the People's Republic of China (hereafter 'China'), and Asian emerging countries more generally, have sharply increased their weight in the automotive supply chain, at the expense of Europe and the United States, it seems that this was largely driven by an increase in demand. Despite their strategic role in providing key inputs such as semiconductors, batteries and rare minerals for batteries, their importance in both traditional and emerging automotive technologies remains limited. The same holds for Central and Eastern European countries.

- The analysis confirms the rapidly growing importance of the green and digital transition in the ecosystem, with a tremendous increase in the number of patents related to autonomous vehicle and, to a lesser extent, to electric vehicle technologies. Hubs in the global automotive value chain, such as Japan, the United States and Germany, are also key players in these emerging technologies. It also highlights the increasing integration of the whole ecosystem, beyond large Original Equipment Manufacturers (OEMs), with a growing role in the technological landscape for young firms and non-automotive firms.
    - Young firms file an increasing share of automotive patents, in particular in autonomous and electric vehicles technologies. They are instrumental in the relationship between academic institutions and businesses and tend to focus on core emerging technologies, whereas older firms are more specialised in the integration of these technologies with the rest of the vehicle. This is consistent with the higher business dynamism in the automotive ecosystem compared to other parts of the economy. Even if the ecosystem is structured around large multinational firms, it displays a solid employment growth, notably driven by the rapid development of young firms and, for some sectors, by higher entry rates.
    - Non automotive firms, and in particular ICT firms, are becoming more central to the automotive ecosystem. The analysis underlines the marked differences between emerging technologies, especially autonomous vehicle technologies and more traditional ones, as they rely on different knowledge bases. As a consequence, ICT firms become an important target of automotive acquirers. More generally, the patent portfolio of firms targeted by M&A transactions is more oriented towards autonomous and electric vehicles technologies.

Historically, the economic weight and the innovative nature of the automotive sector were the main justifications for public interventions. Recent developments have triggered new rationales for supporting the automotive ecosystem. First, the COVID-19 crisis has not only sharply reduced the sector’s demand, but would also have affected the sector’s investment capacity absent any public interventions and policy support, at a time when investment is so dearly needed to cope with the twin green and digital transitions. Second, the recent shortage in semiconductors significantly affected the automotive ecosystem, shedding light on strong dependencies in the automotive value chain, not only on semiconductors but also on some raw materials. Third, rising energy prices due to the Russian Federation’s (hereafter, ‘Russia’) large-scale aggression against Ukraine have affected both supply and demand in the automotive ecosystem, particularly in Europe. Current interventions are therefore focusing on tackling the weakened investment capacity and falling demand, while reducing dependencies. This paper provides recommendations to better take into account the ecosystem dimension in automotive industrial strategies aimed at promoting the green and digital transformations.

- First, this paper highlights the importance of taking into account the whole industrial ecosystem and its evolutions when designing industrial policies. This is all the more important at a time when resilience of value chains is brought at the forefront of policy debates and when the automotive sector increasingly relies on new inputs whose supply is currently concentrated in a few countries (batteries, rare minerals or semi-conductors). The entry of new actors in the automotive ecosystem, allowed by the emergence of new technologies and new business models, also calls for regular updates of the ecosystem boundaries, and therefore of policies related to the automotive sector.
- Second, policies should support the development of young firms. They are instrumental for the twin transitions but also contribute to employment growth in the automotive ecosystem. Automotive strategies should systematically include support to entrepreneurship and young firms, especially as they are more vulnerable to recent shocks such as the COVID-19 crisis. As young firms face more difficulties to access finance, support should include funding mechanisms, covering loans,

early and late stage venture capital. Innovation policies for the automotive ecosystem should encourage industrial clusters where young firms and academic institutions can interact, and facilitate the development of academic spin-offs. This requires a network of cutting-edge universities and research centres to nurture the automotive ecosystem.

- Third, policies should preserve competition in the automotive ecosystem, which was experiencing a significant growth of M&A transactions before the COVID-19 crisis. This can be achieved by ensuring that competition authorities have the adequate tools to monitor and enforce merger control, by providing several exit strategies to young and fast-growing firms (not only the buyout by a larger firm, but also Initial Public Offerings (IPO) or private equity funding). Finally, competition can also be fostered by limiting market segmentation, for instance by international cooperation on regulatory and technical standards on e.g. autonomous vehicles and emissions.
- Finally, demand-side and other framework policies can also significantly contribute to the development and the twin transitions of the automotive ecosystem. For instance, carbon prices, availability of renewable electricity and long term carbon emission targets are necessary to set expectations and trigger investments in low carbon technologies. Investments in infrastructure and skills are key to ensure demand for and deployment of new automotive technologies.

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# 1 Introduction

The automotive sector, defined in the rest of this paper as the 'Manufacture of motor vehicles, trailers and semi-trailers' (ISIC Rev.4 Division 29), is of utmost importance across OECD countries in terms of both value-added and R&D. Beyond the quantity of employment (around 1.1 % of workers are employed in this sector, on average across OECD countries), it is deemed as a source of "good jobs" creating positive externalities for society (better social and economic outcomes, increased cohesiveness …) (Rodrik and Sabel, 2019[1]). Furthermore, this sector is often concentrated in regions where the automotive sector represents a very high share of value added and employment, with these local economies being highly dependent on this activity.

The automotive sector also induces, more than many other sectors, numerous jobs throughout its supply chain. Car manufacturers are in fact at the core of a broader industrial ecosystem (Box 1), which includes suppliers of inputs and capital goods (such as parts manufacturers, machinery, metal production or services providers), related sectors also facing challenges linked to decarbonisation of mobility and sharing some of their technologies (such as railway rolling stock producers), downstream sectors (such as wholesale and retail trade and repair of motor vehicles), and more generally skills, knowledge and framework conditions (including universities, research institutes and labour market institutions). Industrial ecosystems gather entities from several industries and regions, beyond the traditional spatial approach of ecosystems.

The automotive value chain has undergone a significant transformation over the last 25 years. Rising demand in emerging countries coupled with globalisation of value chains resulted in profound changes in the global organisation of production. In countries that were leaders in this sector in the 1990s, this has sometimes been perceived as a threat to 'good jobs' in the automotive sector, a danger for regions with a strong importance of the sector and a potentially destabilising shock to the whole ecosystem.

Governments have closely monitored this transformation and often resorted to sectoral industrial policies in an attempt to smooth the impact on workers, firms and communities. Also motivated by the high technological level of this industry and by potential economies of scale, they supported the local automotive industry in order to maintain a strong industrial base capable of generating long term economic growth by enhancing technological progress.

Nowadays, this sector is one of the most salient examples of an industry simultaneously affected by the green and the digital transitions. This so-called 'twin transition' does not only affect technologies, but also business models, and has the potential to drastically change the structure of the automotive ecosystem. This ongoing revolution calls for a reassessment of policies for the automotive sector and its industrial ecosystem, taking into account new societal challenges, technologies, and business models.

New industrial policies for the automotive ecosystem are growing in recent years, parly resulting from the response to several global shocks. First, the COVID-19 crisis has not only sharply reduced the sector's demand, but would also have affected the sector's investment capacity absent any public interventions and policy support, at a time when investment is so dearly needed to cope with the twin green and digital transitions. Second, the recent shortage in semiconductors significantly affected the automotive ecosystem, shedding light on strong dependencies in the automotive value chain, not only on semiconductors but also on some raw materials that are key for the development of clean vehicles. Third, the automotive ecosystem is also affected by rising energy prices as a consequence of Russia's large-scale aggression against Ukraine.

Building on several data sources such as the OECD's Inter-Country Input-Output (ICIO) tables, patent data, mergers and acquisitions (M&A) transactions, cross-country data from the microdistributed projects Dynemp and Multiprod, and firm-level data, this paper identifies the boundaries of the industrial ecosystem surrounding the automotive sector. In addition, it offers a comprehensive assessment of the changing ecosystem microstructure. Finally, analysing the results through the lens of the conceptual framework developed in previous OECD studies (Anderson et al., 2021[2]; Criscuolo et al., 2022[3]), it provides recommendations to help policymakers better articulate automotive strategies for the green and digital transitions.

The new trends affecting the automotive ecosystem have been extensively discussed in the business/consulting literature. This provides a good basis to understand the technological changes at play in the industry, and their impact on business models. In addition, scholars have also studied the impact of globalisation and the green transition on the sector (Aghion et al., 2016[4]; Gaddi and Garbellini, 2021[5]; Pavlínek, 2019[6]; Russo et al., 2022[7]). For instance, Gaddi and Garbellini (2021[5]) analyse European policies for the automotive sector and conclude that demand-side policies, such as the deployment of charging infrastructure and regulations on vehicles' emissions, are insufficient to ensure the future of the automotive industry in the European Union (EU).

This paper differs from previous contributions by explicitly taking into account the ecosystem dimension and its different layers and by providing novel evidence on the patenting and M&A activities in the ecosystem, as well as its business dynamism. This allows identifying new analytical results and policy messages.

Analysis of linkages allows identifying the sectors that are relevant for the automotive ecosystem:

- Several sectors, notably 'Wholesale and retail trade; repair of motor vehicles and motorcycles', 'Manufacture of rubber and plastics products', 'Manufacture of basic metals' and 'Manufacture of fabricated metal products, except machinery and equipment' are strongly linked with the automotive sector as upstream providers of inputs and value added. Besides, the automotive sector relies, as many other sectors, on a wide range of ancillary business services (e.g. professional, scientific and technical activities, administrative and support services, financial and insurance services).
- In addition to these sectors, analysis of patent and M&A data shows that ICT sectors increasingly contribute to important emerging technologies for the automotive sector, notably for autonomous vehicles. M&A data unveils an increasing volume of transactions involving automotive and ICT firms, mainly with the former acquiring the latter. This confirms that ICT sectors are increasingly linked to the automotive industry, with automotive firms acquiring talent and knowledge through external growth.
- Based on these findings, this paper proposes a definition of the automotive ecosystem encompassing 14 sectors (defined at the 2-digit level of the ISIC Rev.4 classification). The composition of the ecosystem reflects a variety of linkages. It includes upstream sectors providing inputs to the automotive sector (e.g. fabricated metal products, rubber and plastic products), downstream sectors (wholesale and retail trade and repair of motor vehicles), sectors heavily relying on motor vehicles as a capital good (e.g. land transport) and sectors sharing the same technologies or challenges (other transport equipment, ICT). However, as a conceptual framework to define industrial ecosystems and identify their boundaries is lacking, this definition, even if based on analytical results, partly rests on arbitrary choices.

The analysis also underlines several messages regarding the changing microstructure of the ecosystem, such as the shift towards emerging Asian countries of the automotive supply chain, which has not been accompanied yet by a significant breakthrough of these countries in automotive technologies, and, within Europe the shift towards Central and Eastern European countries, at the expense of several large European countries; the rapidly growing importance of the green and digital transitions in the ecosystem, partly driven by young and by non-automotive firms; and the higher business dynamism of the ecosystem compared to other sectors of the economy.

These results allow drawing several conclusions for policy makers on the importance of taking into account the whole industrial ecosystem and its evolutions when designing industrial policies, on the importance of policies to support the development of young firms (for instance by making adequate funding available or by facilitating exchanges with the academic sphere), and on the need to preserve competition in the automotive ecosystem, which was experiencing a significant growth of M&A transactions before the COVID-19 crisis (e.g. by ensuring that competition authorities gave the adequate tools to monitor merger and enforce their control, or by offering young firms several exit options, beyond the buyout by a large established firm). These policies are complementary to other crucial horizontal support such as investment in the required skills and infrastructure (e.g. 5G or charging infrastructure) and a clear policy direction for the green transition (including for instance carbon price signals and bold sectoral emission targets).

This paper starts by exploring the automotive value chain and its transformation over the last twenty-five years in section 2. After reviewing the business literature on the effect of the evolution of Connected, Automated, Shared and Electric (CASE) vehicles in section 3, sections 4 provides new evidence on the impact of the green and digital transitions on the automotive ecosystem using patent data, completed by evidence from M&A data in section 5. Armed with this evidence, section 6 proposes a set of sectors that can be considered as part of the automotive ecosystem. Productivity and business dynamism in these sectors are explored in section 7. After a discussion of the latest automotive strategies in four countries and building on the analytical results obtained in the previous sections, section 8 concludes with the main policy messages.

### Box 1. Industrial ecosystems and their role for industrial policy

The European Commission considers that industrial ecosystems "encompass all players operating in a value chain: from the smallest start-ups to the largest companies, from academia to research, service providers to suppliers" (European Commission, 2020[8]). This definition is consistent with the academic literature (Andreoni, 2018[9]) on industrial ecosystems, which underlines the heterogeneity of players (public vs private, firms of different sizes) and their interdependency. This literature also stresses that industrial ecosystems can gather entities from several industries and regions, thereby departing from traditional spatial approaches.

Beyond the production network (input-output linkages), industrial ecosystems consist of investment networks (e.g. inter-sectoral flows of tangible and intangible capital goods), knowledge networks (based on R&D activity, patent development, relationships with universities and research centres, etc.), and financial networks (M&A, VC investment, etc.), with different types of firms (e.g. start-ups and multinational enterprises) and public and private institutions (e.g. universities) having different roles in each layer.

These different layers can reveal the directionality of ecosystems in a way that traditional input-output analysis cannot. Indeed, while input-output relationships can uncover production flows, they cannot reveal emerging trends in the industry, in particular those linked to the green and digital transitions. In contrast, financial flows can reveal information on the expectations of the ecosystem's market players. For example, investments from major players in a sector into innovative start-ups in other sectors present clues as to the evolution of both sectors. Furthermore, knowledge networks can reveal the technological innovations led by sectors with similar green and digital challenges, and inform about future directions of sectoral technological progress with its corresponding linkage to public research.

To maximise the impact of industrial policy on industrial ecosystems, a granular analysis of these networks, based on detailed and multifaceted data is required. Such an analysis can then support the implementation of more effective policies, regulations and resources, in order to:

- Drive the twin transition, by identifying areas where strategic policy action needs to influence market trends in order to ensure the digital and environmental future of specific industries;
- Further technological and scientific leadership, by understanding R&D trends and encouraging entrepreneurship;
- Assess the resilience of industrial ecosystems and build strategic autonomy, by identifying interdependencies, concentrations and power asymmetries;
- Encourage competition while supporting investment, by identifying sectors that need support without interfering with healthy market forces;
- Foster the effectiveness and efficiency of industrial policy, through informed, targeted and timely interventions with a view to long term impact.

Beyond policy-making, the business literature increasingly recognises and uses the concept of industrial ecosystem (Deloitte, 2016[10]; McKinsey & Company and Fraunhofer, 2020[11]), as business investment decisions are more and more interdependent (e.g. data sharing along the value chain, product sustainability or adoption of emerging technologies).

Finally, the European Commission considers that the automotive sector is part of the ‘Mobility-Transport-Automotive’ ecosystem (see Box 4), which includes notably the production of railway rolling stock, shipbuilding, ‘Wholesale and retail trade and repair of motor vehicles and motorcycles’ and part of ‘Land transport and transport via pipelines’.

# 2 The automotive value chain experienced significant changes over the last 25 years

Sectors of an industrial ecosystem are interlinked in many ways. Among those linkages, input-output relationships are key and studied in this sector. The first subsection describes the automotive value chain, while the second subsection elaborates on its economic weight in terms of value added, employment, productivity and R&D. The last subsection describes the global reallocation of demand and supply over the last 25 years and its impact on the value chain.

This section shows that several sectors, notably ‘Wholesale and retail trade; repair of motor vehicles and motorcycles’, ‘Manufacture of rubber and plastics products’, ‘Manufacture of basic metals’ and ‘Manufacture of fabricated metal products, except machinery and equipment’ are strongly linked with the automotive sector as upstream providers of inputs and value added. Besides, the automotive sector relies, as many other sectors, on a wide range of ancillary business services (e.g. professional, scientific and technical activities, administrative and support services, financial and insurance services).

It also highlights that Asian emerging countries have sharply increased their weight in the automotive supply chain, at the expense of the United States and Europe, with the notable exception of Germany.

## The automotive value chain

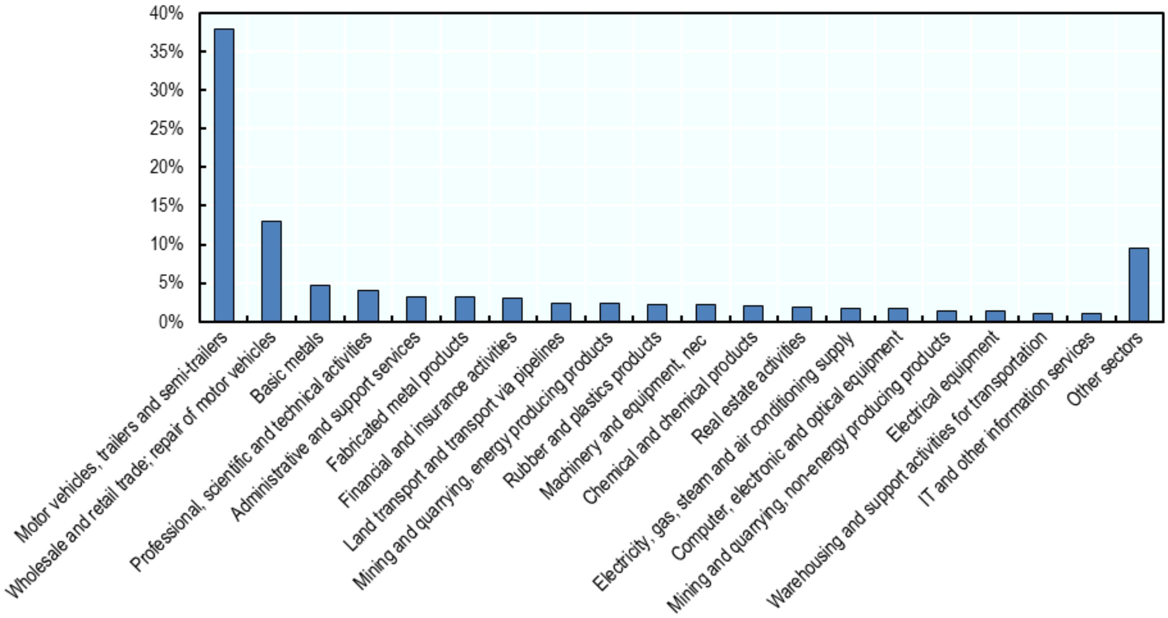
This subsection starts by describing the upstream sectors linked to the automotive sector, and then discusses downstream linkages.

### *The automotive sector has strong linkages with several upstream sectors*

The production of motor vehicles relies on a large number of inputs, which are important for the automotive value chain. Only 38 % of value added embodied in motor vehicles is produced by the automotive sector itself (Figure 1). The rest comes from services (e.g. Wholesale and retail trade; repair of motor vehicles and motorcycles – 13 % of the value added – or Professional, scientific and technical activities – 4 % of the value added) and upstream manufacturing activities (e.g. Basic metals – 5 % of the value added – or Fabricated metal products – 3 % of the value added). Importantly, production of motor vehicles relies on a large number of horizontal sectors that contribute to several other value chains (e.g. energy, business services and financial services). These sectors represent 37% of the value added incorporated in motor vehicles.

### Figure 1. Sectoral composition of the value added embodied in motor vehicles

Value added embodied in global final demand for motor vehicles, by sector, as a share of global final demand for motor vehicles, 2018

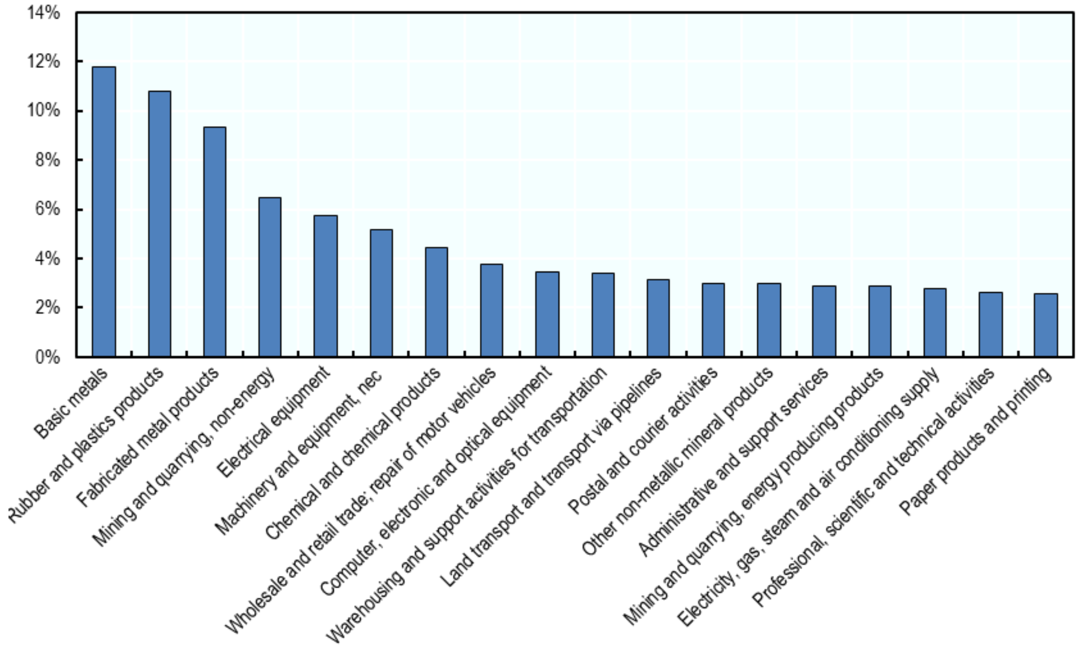



Note: This graph describes the composition of global final demand in motor vehicles, by sector of origin. 38 % of the value-added embodied in motor vehicles comes from the 'Motor vehicles, trailers and semi-trailers' sector (ISIC Rev.4 Division 29) and 13 % from the 'Wholesale and retail trade; repair of motor vehicles and motorcycles' sector (ISIC Rev.4 Divisions 45 to 47).
Source: OECD, Trade in Value Added (TiVA) Database, http://oe.cd/TiVA, February 2022.

Another perspective is the extent to which sectors rely on the automotive value chain. For certain upstream manufacturing activities, around 10% of their value added can be linked to the automotive value chain, notably Basic metals (12%), Rubber and plastic products (11%) and Fabricated metal products (9%), see Figure 2. Horizontal service activities, despite contributing significantly to total value added embodied in motor vehicles, are much less dependent on this value chain.

## Figure 2. Share of sectoral value added linked to the automotive value chain

Value added embodied in global final demand for motor vehicles, by sector, as a share of sectoral value added, 2018

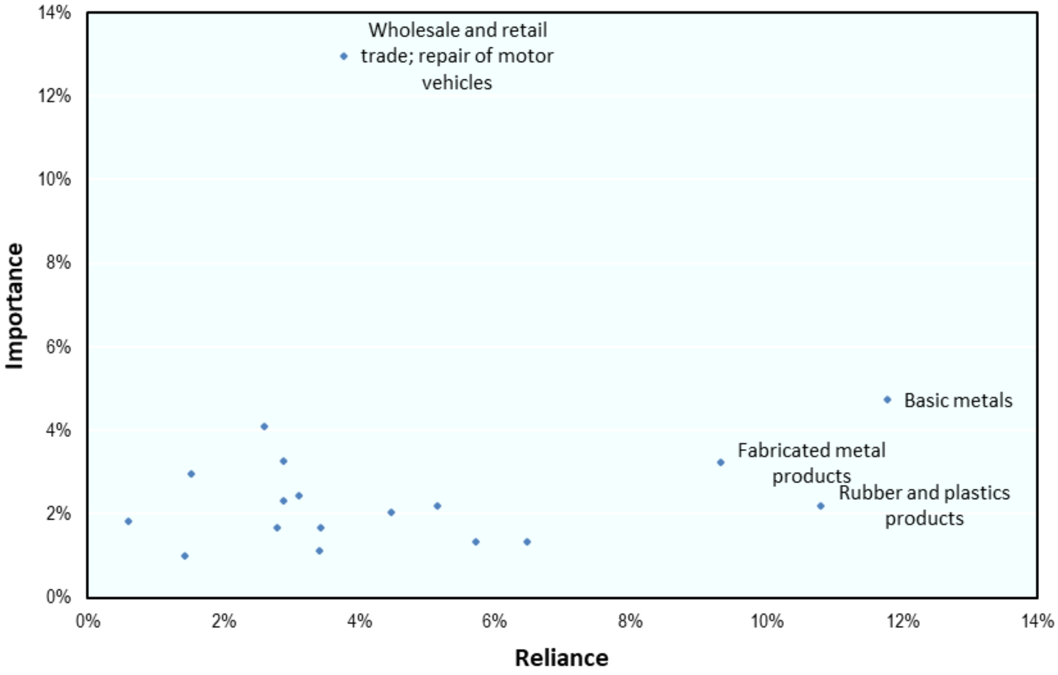



Note: 12% of the value added produced in the 'Basic metals' sector worldwide is embodied in global final demand for motor vehicles. For the sake of readability, this graph does not include the 'Motor vehicles, trailers and semi-trailers' sector. 80% of its worldwide value added is embodied in global final demand of motor vehicles.
Source: OECD, Trade in Value Added (TiVA) Database, http://oe.cd/TiVA, February 2022.

Combining the two criteria (importance for the automotive value chain and reliance on its value chain), it is possible to identify four sectors that appear to be particularly connected with the automotive value chain (Figure 3):

- First, 'Wholesale and retail trade; repair of motor vehicles and motorcycles' (ISIC Rev.4 Divisions 45 to 47) is by far the most important sector for the automotive value chain. Even if more disaggregated data are not available in the TiVA database, 'Wholesale and retail trade and repair of motor vehicles and motorcycles' (Division 45) is probably the most relevant part of this sector for the automotive value chain, since it is directly involved in commercialisation and maintenance of motor vehicles.
- Second, three manufacturing sectors appear to rely heavily on the automotive value chain:
  - 'Manufacture of rubber and plastics products' (ISIC Rev.4 Division 22),
  - 'Manufacture of basic metals' (ISIC Rev.4 Division 24) and
  - 'Manufacture of fabricated metal products, except machinery and equipment' (ISIC Rev.4 Division 25).

### Figure 3. Importance for and reliance on the automotive value chain, 2018




Note: Importance = Value added embodied in global final demand for motor vehicles, by sector, as a share of global final demand, see Figure 1. Reliance = Value added embodied in global final demand for motor vehicles, by sector, as a share of sectoral value added, see Figure 2.
Source: OECD, Trade in Value Added (TiVA) Database, http://oe.cd/TiVA, February 2022.

### *Linkages with downstream sectors are less important*

Conversely, value added produced in the motor vehicle sector does not contribute significantly to other final products. More than 80% of the value added of the sector is embodied in the global final demand for motor vehicles. The second most important final product is 'Construction' (ISIC Rev.4 Divisions 41 to 43), but it accounts for only 3 % of the value added of the motor vehicle sector.

In the same vein, none of the downstream sectors heavily relies on value added produced in the motor vehicle sector. The final demand for 'Manufacture of machinery and equipment n.e.c.' is the most dependent on automotive value-added, but the latter accounts for only 1% of the global final demand for machinery and equipment.

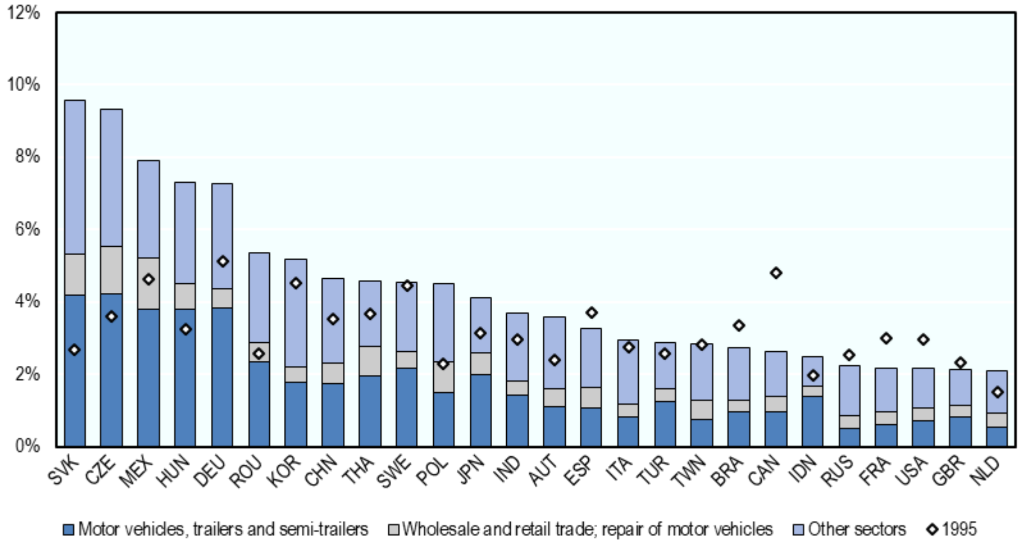
As they only trace intermediate consumption, input-output linkages do not allow the identification of the sectors that rely on automotive as an investment good (such as land transport). This is discussed further in Section 6.

## The automotive sector and its value chain as an economic heavyweight

The automotive sector and its value chain represent a high share of total value added in many OECD and non-OECD economies (Figure 4), with the highest contributions coming directly from the production of motor vehicles and from the 'Wholesale, retail trade and repair of motor vehicles' sector. The automotive value chain is of uttermost importance for Central and Eastern European (CEE) countries such as Slovakia, Czech Republic and Hungary, where it represents 10%, 9% and 7% of domestic value added respectively; and in large economies such as Mexico and Germany where it represents 8% and 7% of domestic value added respectively. Moreover, the automotive value chain has increased its economic contribution from 3.2% of national value added on average in 1995 to 4.3% in 2018 for the economies represented in Figure 4.

## Figure 4. Share of national value added embodied in global final demand for motor vehicles

Value added embodied in global final demand for motor vehicles, by economy and sector, as a share of national value added, 1995 and 2018. Sample of selected economies.



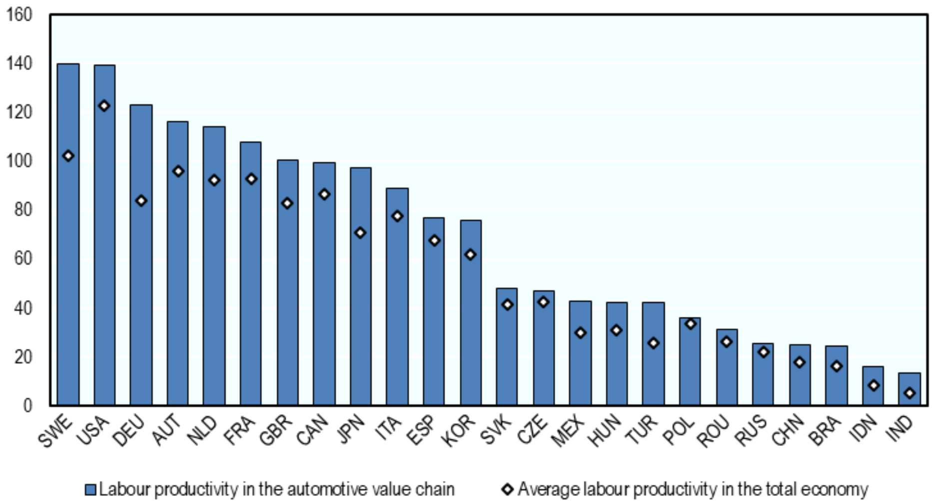

Note: In Slovakia, 9.6% of domestic value added is embodied in the global final demand for motor vehicles. Among these 9.6 percentage points, 4.2 come from the automotive sector, 1.1 from the wholesale and retail trade and repair of motor vehicles and 4.3 from other sectors. The sample is composed of the 26 economies with the highest amount of domestic value added (in dollars) embodied in global final demand for motor vehicles.

Source: OECD, Trade in Value-Added (TiVA) Database, oe.cd/TiVA, February 2022.

Despite its important contribution to national employment, the automotive value chain employment contribution is lower than its value added counterpart (Annex B). Hence, labour productivity of the automotive sector and its value chain is higher than average (Figure 5), thereby reflecting the relative high "quality" of jobs in this value chain. Therefore, even if the automotive value chain accounts for a relatively moderate number of jobs in the economy, the quality and skill level of these jobs seem to justify specific policies (see Section 8).

## Figure 5. Labour productivity in the automotive value chain is higher than in the rest of the economy

Value added per worker in the automotive value chain compared with the total economy average, 2018, thousand USD per worker.

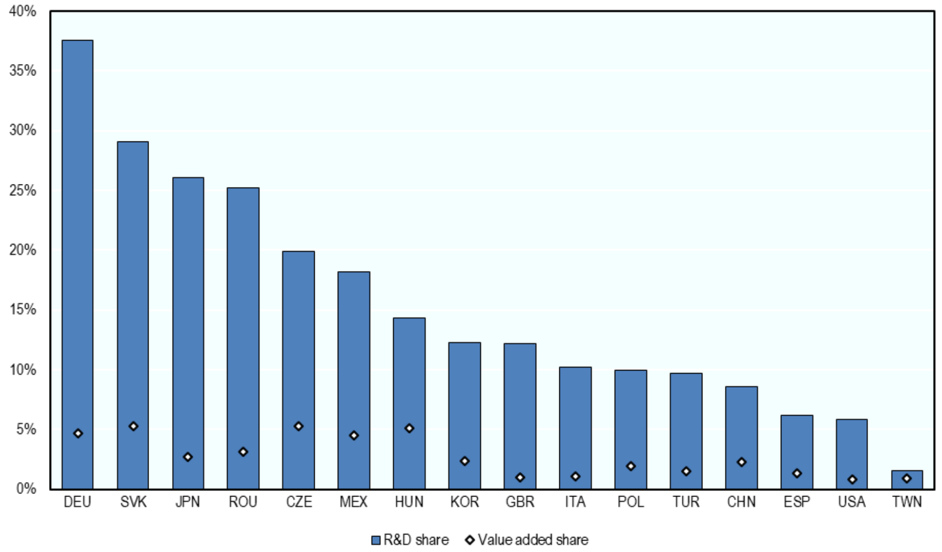



Note: Labour productivity is calculated by dividing domestic value added embodied in the global final demand for motor vehicles by domestic employment embodied in the global final demand for motor vehicles. The sample is the same as in Figure 4 but with fewer economies due to availability of employment data.
Source: OECD, Trade in Value-Added (TiVA) and Trade in Employment (TiM) Databases, oe.cd/tiva and oe.cd/io-emp , February 2022.

Linked to the high labour productivity of automotive jobs, the automotive sector also represents a significant share of business R&D expenditures (Figure 6). In a vast majority of economies, the share of the automotive sector in business R&D expenditures is higher than its share in economy-wide value added[1]. Moreover, the automotive sector is the third contributor to R&D investment by the top 2000 R&D investors worldwide and the sector with the highest number of patents filed out by these investors (OECD, 2021[12]). The higher than average productivity and R&D intensity provide an important justification for policy intervention, which could produce knowledge spillovers, with potential benefits for long term economic growth.

### Figure 6. The automotive sector represents an important share of business R&D

Share of the automotive sector in total business R&D expenditures compared with its share in total value added, 2018




Note: Economies are included in the sample based on data availability. In Germany, R&D expenditures of the automotive sector represent 38% of total business R&D expenditures, which are higher than the share of this sector in value added (5%).
Source: OECD, ANBERD Database, http://oe.cd/anberd, February 2022.

## A significant shift towards Asia has occurred over the last 25 years

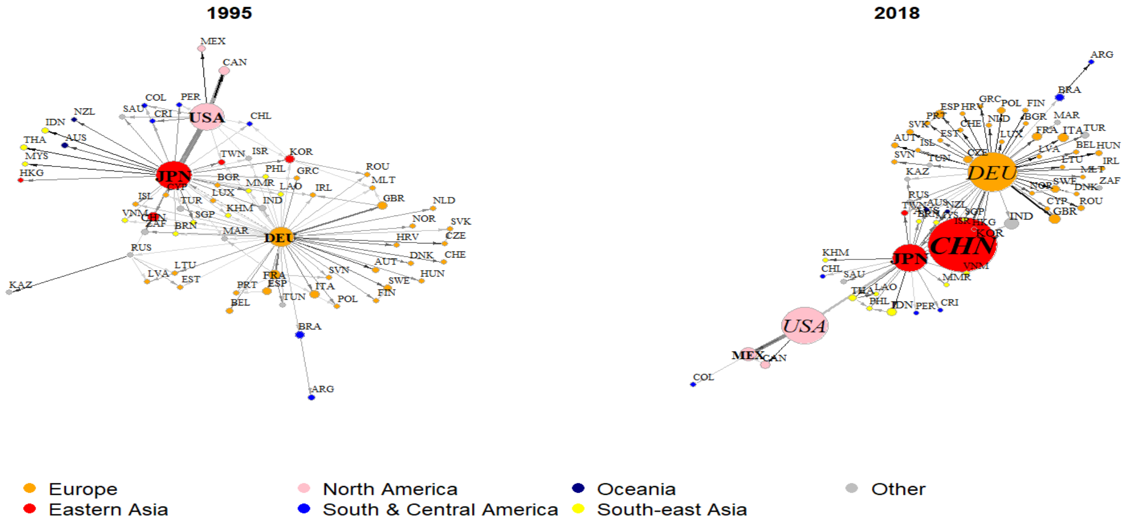
Over the last 25 years, the automotive value chain has experienced a significant reallocation of production across regions (Figure 7) reflecting, among other factors, a gradual change in both supply and demand, enhanced by the growing importance of global value chains (GVCs) (OECD, 2020[13]).[2]

The most striking feature is the emergence of China as a global supplier and customer of value added embodied in motor vehicles. However, Japan remains the most connected node in Asia given its high number of supply linkages with other countries in the region. China has fewer linkages and its supply mainly serves its large domestic market. Nevertheless, China is becoming the main regional demand hub in Asia and a major global demand centre.

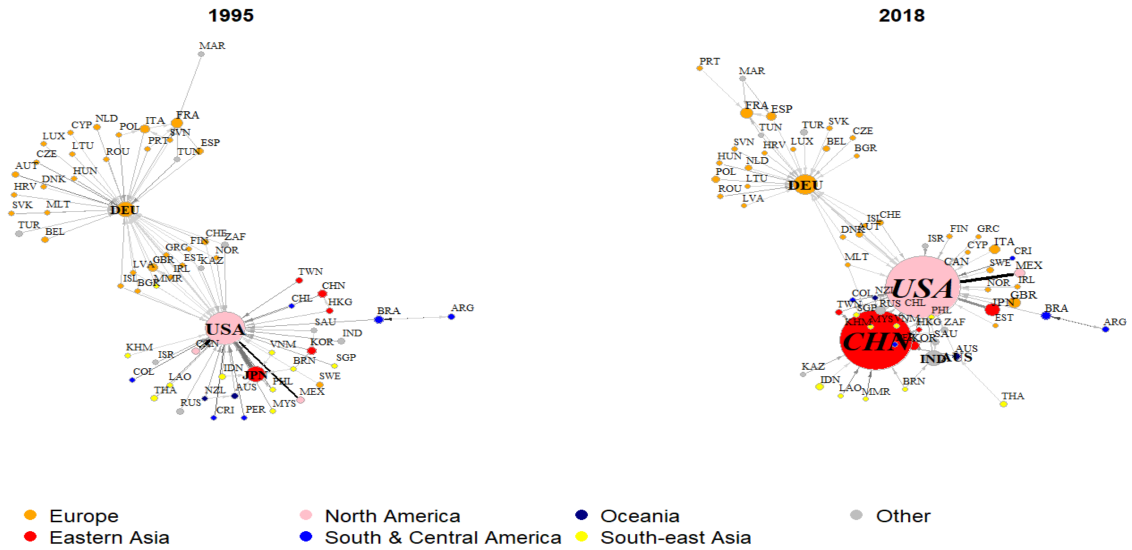
Figure 7 also demonstrates that the global automotive value chain remains organised around regional hubs, notably in Europe (around Germany), America (around the United States) and Asia (around China and Japan). Another relevant phenomenon is the emergence of secondary supply hubs in some regions, such as Mexico in North America and India in Asia.

## Figure 7. China has become a major player in the automotive value chain

Supply network of value added embodied in global final demand for motor vehicles in 1995 and 2018




Demand network of value added embodied in global final demand for motor vehicles in 1995 and 2018



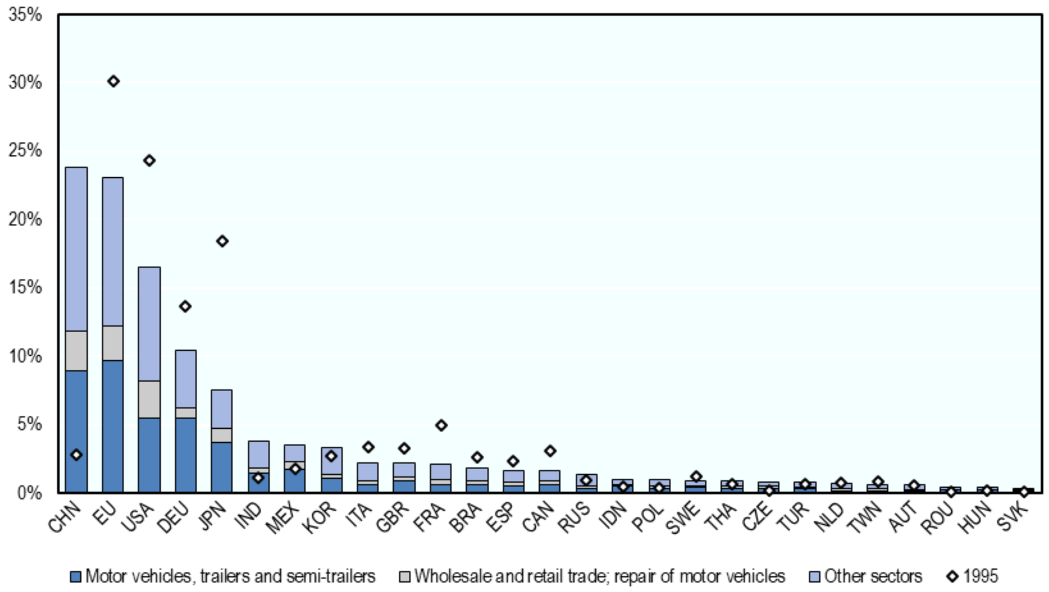

Note: In the supply network, the size of nodes corresponds to each economy's domestic value added in motor vehicles. In the demand network, the size of nodes corresponds to each economy's final demand for motor vehicles. In both networks, an edge from economy X to economy Y represents the value added in economy X embodied in economy Y's final demand. The edges in the supply network shows value added from the motor vehicle industry in economy X used by economy Y in its final demand. The edges in the demand network shows the magnitude of value added sourced from any industries of economy X embodied in final demand for motor vehicles in economy Y. Only the most important edges are displayed. In the supply network, edges are shown if economy X is the largest motor vehicle value added supplier to economy Y, or if economy X contributes to at least 15% of the motor vehicle foreign value added in economy Y's final demand. In the demand network, edges are shown if economy Y is the largest consumer of value added embodied in the final demand of motor vehicle from economy X, or if economy Y absorbs at least 15% of economy X's value added embodied in the foreign final demand for motor vehicles.

Source: (Han and Yamano, 2023, forthcoming[14]) based on OECD Inter-Country Input-Output Database, http://oe.cd/icio.

As China has increased its weight in the automotive value chain, mainly through value added meeting its increasing domestic demand, the weights of the European Union, the United States and Japan have decreased (Figure 8).

### Figure 8. An important reallocation of value added across regions has taken place since 1995

Value added embodied in global final demand for motor vehicles, by economy and sector, as a share of global final demand for motor vehicles, 1995 and 2018




Note: 24% of global value added embodied in final demand for motor vehicles comes from China. Among these, 9 percentage points are coming from the automotive sector, 3 percentage points from wholesale and retail trade and repair of motor vehicles and 12 percentage points from other sectors.

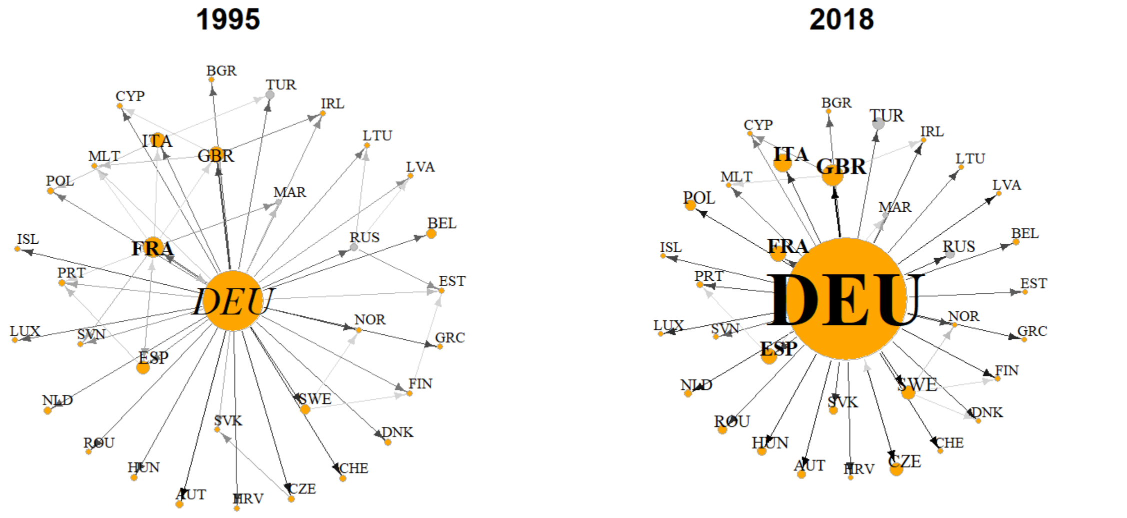
Source: OECD, Trade in Value-Added (TiVA) Database, oe.cd/TiVA, February 2022.

## Reallocation of production in the European automotive value chain: Different offshoring strategies

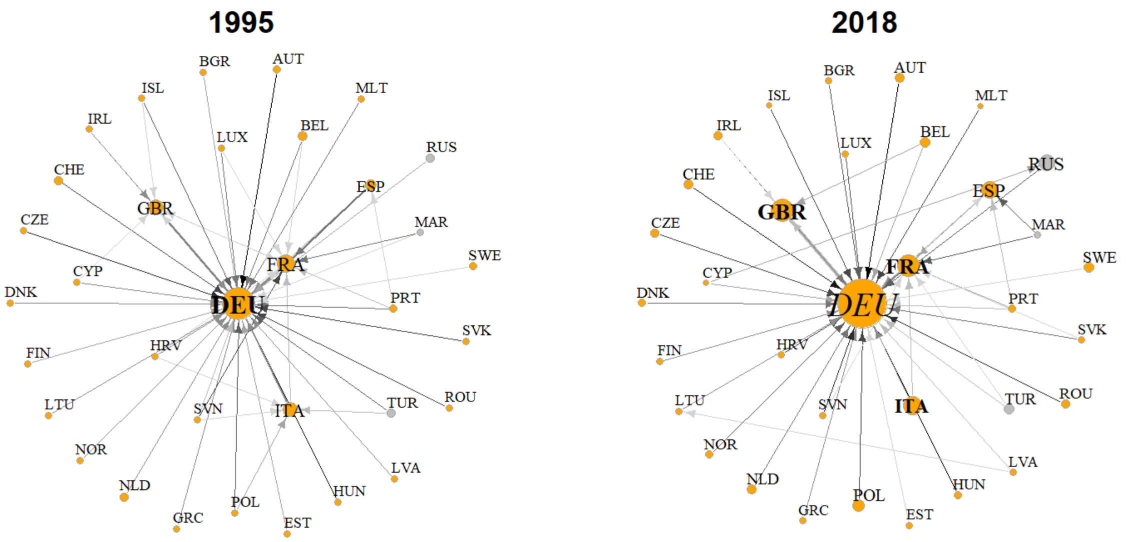
The European automotive value chain (including Türkiye and Morocco as these countries are important suppliers for the European market) is a well-interconnected network of countries with strong supply and demand linkages. Inside this network, the main supply and demand hub remains Germany (Figure 9), while France, Italy, the United Kingdom, Sweden, Spain and CEE countries are also important.

## Figure 9. Germany has maintained its position as the main supply and demand hub

Supply network of value added embodied in final demand for motor vehicles in 1995 and 2018




Demand network of value added embodied in final demand for motor vehicles in 1995 and 2018

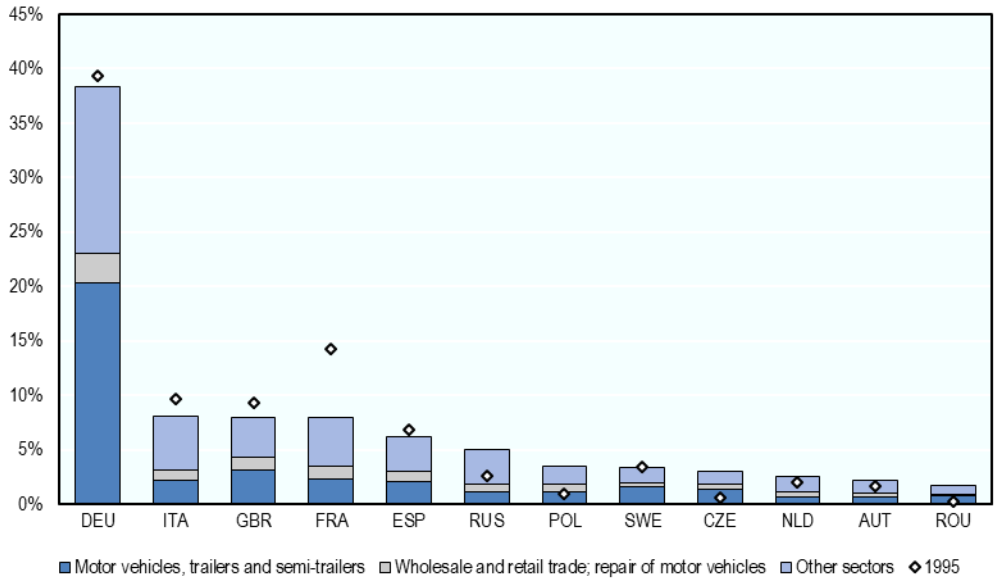



Note: Same as in Figure 7.
Source: (Han and Yamano, 2023, forthcoming[14]) based on OECD Inter-Country Input-Output Database, http://oe.cd/icio.

A reallocation of value added has taken place within the European automotive value chain from countries such as France and Italy towards CEE countries such as Poland, Czech Republic, Romania, Slovakia and Hungary. However, Germany has been resilient to this trend, maintaining its position as the main supply hub in the EU automotive value chain (Figure 9 and Figure 10). This could reflect the distinctive approach followed by German car producers, which mainly moved the middle stages[3] of the production process to other European countries (mainly CEE countries), rather than entire parts of the process as in France and Italy (Fana and Villani, 2021[15]; Balcet and Ietto-Gillies, 2019[16]; Chiappini, 2012[17]). Offshoring patterns in the European automotive sector are further analysed in Box 2.

### Figure 10. A reallocation of value added in the automotive value chain has taken place in Europe, but Germany has maintained its leadership position

Value added embodied in global final demand for motor vehicles, by country and sector, as a share of European value added embodied in global final demand for motor vehicles, 1995 and 2018




Note: Germany contributes to 39% of the European value added meeting global final demand for motor vehicles. Among these, 20 percentage points are coming from motor vehicles, 3 percentage points from wholesale and retail trade and repair of motor vehicles and 15 percentage points from other sectors.
Source: OECD, Trade in Value-Added (TiVA) Database, oe.cd/TiVA, February 2022.

### Box 2. Different offshoring patterns in the automotive sector of European countries

France and Italy have offshored almost all stages of the production process while Germany has only offshored the middle stages, keeping the production steps with high technological content in the country (Fana and Villani, 2021[15]; Pavlínek, 2012[18])[4]. This offshoring process has been driven by some big players in the industry, such as Renault in France (Chiappini, 2012[17]) and Fiat in Italy (Bundesbank, 2011[19]; Simonazzi, Ginzburg and Nocella, 2013[20]), whose strategies can determine the overall trends in the industry given the oligopolistic nature of the automotive market.

Fana and Villani (2021[15]) argue that the success of the German offshoring strategy was not only driven by the reduction of wage costs, but also by the combination of solid technological improvements in Germany[5] (Simonazzi, Ginzburg and Nocella, 2013[20]; Vermeiren, 2017[21]) and by the German positioning on more complex, exclusive and customised products (Simonazzi, Ginzburg and Nocella, 2013[20]). German firms have exploited new production and cost cutting opportunities from offshored activites, which are complementary to the activities in Germany. Marin (2010[22]) and Hansen (2010[23]) have empirically shown how offshoring towards CEE countries contributed to German export growth by increasing the productivity of parent companies.

Contrary to France and Italy where offshoring resulted in a decrease of output, automotive production increased in the United Kingdom (KPMG, 2014[24]). Unlike in France, Germany and Italy, British automotive production does not rely on domestic brands only, but also on several foreign companies

(Holweg, 2009[25]), which are specialised in downstream activities (e.g. Nissan and Toyota) whereas domestic companies are more specialised in upstream activities (Qamar et al., 2021[26]).

In summary, the positive impact of offshoring for the German automotive ecosystem might be driven by the technological sophistication of German cars and by Germany's partial offshoring strategy, focused on production stages with the lowest technological intensity. This is consistent with Figure 14 (Section 4), which shows that Relative Technology Advantage (RTA) in automotive technologies has remained high in Germany relative to France, Italy and the United Kingdom.

# 3 The automotive ecosystem is simultaneously affected by the green and digital transformations

Over the last 25 years, the automotive ecosystem has been experiencing a dramatic industrial transformation, driven by both supply and demand. Going forward, key trends, driven by the green and digital transformations, are changing business models towards a new paradigm, sometimes referred to as CASE (connected, autonomous, shared, electric vehicles). This section summarises the business literature on these trends and their expected impact on business models in the automotive ecosystem.

## The twin transitions are driving the 'CASE' revolution

The business literature often summarises evolutions affecting the automotive ecosystem through the acronym 'CASE' (Connected, Automated, Shared and Electric)[6]. Although perhaps less pervasive, the ecosystem is also affected by the Robotisation (R) of production and the long run evolution of Urban (U) mobility (CASE+RU).

**Connected**. According to PwC (2021[27]), in the European Union and the United States nearly half of the vehicle park will be connected by 2025. Connected vehicles are likely to offer a large portfolio of digital services related to navigation, safety, vehicle management, information and entertainment, among others (PwC, 2021[27]), and will generate a growing flow of data.

**Automated**. A few years ago, commercialisation of fully-automated vehicles was expected for 2025 (BCG, 2015[28]). Even if it is now more realistic to expect them for 2035 (PwC, 2021[27]), recent years have witnessed the commercialisation of the first level-3 vehicles[7]. Level-3 and above vehicles are expected to represent almost one third of sales in 2035.

**Shared**. Prompted by an increase in the price of vehicles and their complexity, customers would tend to own fewer vehicles and instead rent them (classic rental, short-term rental such as car sharing, long-term rental such as operational leasing). In 2019, 1 out of 4 new car registrations is for a leasing or rental vehicle, compared to 1 out of 6 in 2014[8]. The market for rental, leasing and car-sharing is expected to continue to grow in the coming years[9], especially in Europe and Japan, where it would represent more than 25% of passenger traffic in 2035 (PwC, 2021[27]).

**Electric.** Sales of electric vehicles took off during the COVID-19 crisis, partly owing to generous purchase support enacted in several countries (see Section 8). Electric car sales have reached a record high in 2020 in spite of the COVID-19 crisis, although their market share reaches a mere 4.6% globally (IEA, 2021[29]). Zero-emission electric vehicles can be equipped with several types of powertrain. Batteries electric vehicles (BEVs) are the most common in 2021, followed by plug-in hybrid electric vehicles (PHEVs). Both rely on batteries that need to be charged by being plugged into the power grid, but PHEVs also have an internal combustion engine (ICE). As the latter are potentially zero-emission vehicles when using the electric engine, their emissions crucially depend on the use of the ICE, which in turn depends on the charging behaviour and capacity of users, and therefore availability, cost and reliability of charging infrastructure. Finally, fuel-cell electric vehicles (FCEVs) rely on a hydrogen-powered electric engine. These vehicles, whose share in sales remain marginal, do not require charging but need to be filled up with hydrogen, and thereby rely on the availability of hydrogen fuelling stations. FCEVs may be more efficient than batteries to decarbonise heavy transport (Cammeraat, Dechezleprêtre and Lalanne, 2022[30]). The market penetration of electric vehicles is highly dependent on infrastructure, purchase incentives, emission regulations and carbon prices, but could represent the majority of new vehicles sales in 2035 (PwC, 2021[27]).

**Robotisation.** Automotive production is known for being prone to robotisation (De Backer et al., 2018[31]). With the diffusion of Industry 4.0 technologies, notably the use of new control devices, low cost sensors underpinning the internet of things and machine learning (OECD, 2017[32]), robotisation is likely to continue in the near future, thereby deeply affecting production techniques and labour demand.

**Urban mobility**. As the landscape of urban mobility is evolving, the role of cars (and in particular privately-owned cars) in city centres is being questioned. To limit negative externalities (e.g. congestion, health and environmental effects), governments and local authorities are implementing a wide range of policy instruments to reduce the use of private motor vehicles, such as speed limits, urban vehicle restriction schemes, parking pricing and regulations, and road pricing mechanisms. These restrictions are in some cases eased for zero- or low-emission vehicles. The role of private motor vehicles in urban mobility could be reduced from one half of urban passenger-kilometer travelled in 2015 to one third in 2050 (ITF, 2021[33]), potentially with considerable heterogeneity across regions (McKinsey, 2020[34]). Regional and intercity mobility is also likely to undergo significant changes, with a decreasing share of private motor vehicles, but expected policies seem less drastic and could rely more on the pricing of externalities (e.g. carbon pricing).

Although these six evolutions are the most cited trends in the business and mobility literature, they are definitely intertwined. For instance:

- The shifts towards connected and automated vehicles are interrelated. Demand for vehicle connectivity is increased by autonomous driving features. First, automation may require navigation information (for instance relying on communication infrastructure such as 5G networks) in real time to be able to detect or interact with road infrastructure and other vehicles. Second, if passengers are not required to monitor the driving task, vehicles can offer a large portfolio of online services, related to both leisure and work (PwC, 2020[35]).
- The rising importance of shared vehicles could be fostered by the advent of electric and automated vehicles. First, as these technologies are only emerging and may create anxiety for consumers, shared vehicles could be a solution to overcome conservative buying behaviours (Ziegler and Abdelkafi, 2022[36]). Second, as these technologies increase fixed costs (purchase price) but lower marginal costs (e.g. energy costs) of vehicle use, cars are becoming more amenable to shared ownership.

## Business models will be heavily impacted by the CASE+RU trends

These trends will have major impacts on the ecosystem (Figure 11).

1. High investment levels are needed, in particular in the short run as firms need to develop new (electrified) powertrains and new automated driving functions, while they continue improving the performance of internal combustion engines (McKinsey, 2013[37]). This requires a mutualisation of R&D and investment costs, for instance through new partnerships, cooperation, alliances, joint-ventures or mergers (see (McKinsey, 2019[38]) and Section 5).
2. New competitors. As the ‘CASE’ revolution relies on new know-how, technologies (software[10] and artificial intelligence, electric powertrains) and skills, traditional OEMs could face the competition

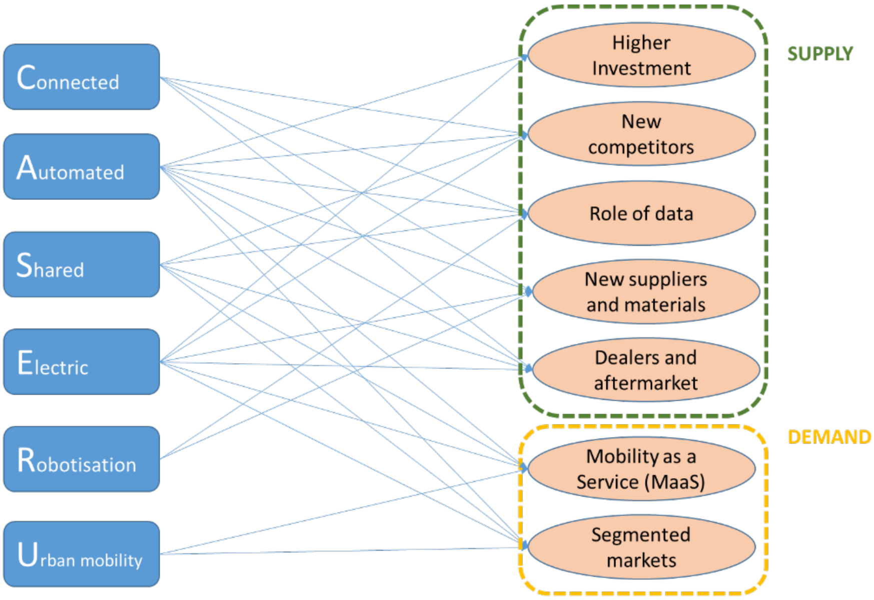
of new entrants. In recent years for instance, the development of self-driving cars algorithms and the take off of BEVs have allowed new firms to demonstrate their technological leadership (e.g. Alphabet's Waymo) or even their ability to gain market shares (e.g. Tesla). Key branding elements may also change, from engines to customer experience, and favour the entry of new competitors. As ICEs were important vectors of differentiation, it is likely that electric engines will be much more standardised.

3. Role of data. The increasing volume of data in the automotive ecosystem is likely to significantly affect business models. On the one hand, data are becoming an important input in the automotive industry, e.g. for the development of autonomous driving algorithms, the management of shared fleets or in smart and robotised factories. On the other hand, data will likely become an important output, as cars' sensors in connected or autonomous vehicles are producing an exponentially growing volume of data, which can be shared with or sold to partners (e.g. insurance or ICT companies). Additionally, this raises the question of data governance and interoperability.
4. New suppliers and materials. The ongoing trends are likely to affect the upstream value-chain. First, the shift to EVs will significantly reduce the number of parts compared to internal combustion engine (ICE) vehicles (IEA, 2019[39]; Deloitte, 2021[40]) and might drastically change the structure of the automotive value chain (e.g. commoditisation of some parts). Second, EV vehicles, and in particular batteries, rely on raw materials which are produced in a small number of countries (European Commission, 2017[41]; European Commission, 2021[42]; Gaddi and Garbellini, 2021[5]; The White House, 2021[43]; Koyamparambath et al., 2022[44]), thereby raising in several OECD countries the issue of dependencies. Third, further robotisation of production processes could affect the geographic location of the value chain. As wage costs are becoming less important, offshoring of production to low-wage countries could be partly reversed (Krenz, Prettner and Strulik, 2021[45]; Faber, 2020[46]). Finally, the shift to connected and automated vehicles will increase the ecosystem's reliance on semiconductor production (see (Guilhoto et al., forth.[47]) and Box 5).
5. Dealers and aftermarket. These trends are also likely to affect the downstream part of the value chain. First, car dealers are increasingly competing with e-commerce, and affected by the growing importance of B-to-B sales. For instance, the number of dealers already decreased by more than 10% in Europe between 2007 and 2013 (European Commission, 2017[41]). Second, aftermarket operators can also be impacted by the shift to shared ownership and will need to adapt to new technologies (e.g. electric powertrains, equipment enabling autonomous driving, etc.). Third, land transport will also be affected by automation in public transport. As these three sectors are labour-intensive, they may concentrate the largest job reallocations and losses stemming from the CASE revolution, and require important investments for reskilling their workers.
6. Mobility as a service. Driven by the emergence of new consumption patterns for cars, private ownership could become less prevalent over the next decades. This trend may be reinforced by increasing car prices linked to autonomous and electric vehicles, but also in some regions by measures restricting the use of private cars in city centres. Against this backdrop, firms in the automotive ecosystem could progressively shift to subscription models, thereby selling a service (maintenance, energy provision, infrastructure … - e.g. Care by Volvo or Volkswagen's charging networks - ID. Charger, We Charge and IONITY) rather than the vehicle itself, or see the entry of new intermediaries (van den Berg, Meurs and Verhoef, 2022[48]).
7. More segmented markets. Market segmentation is likely to grow in a context of cross-country divergence between regulatory environments and an increasing number of technologies (e.g. various powertrains and cars with different degrees of automation).
   a. First, with the rise of shared ownership, the share of 'B-to-B' transactions is likely to grow for automotive firms. As the adoption speed of new powertrains and autonomous driving is likely to differ across professional vehicle fleets, shared fleets[11] and private vehicles, this trend can contribute to the segmentation of the market.

b. Second, implications of new technologies and new consumption patterns can differ across vehicle segments (McKinsey, 2013[37]). For instance, the impact of shared mobility is likely to be greatest on small cars, whereas autonomous driving cars could enter the market through premium vehicles first, as was the case for PHEVs.

c. Third, the diffusion of new technologies is likely to differ across countries. Both driven by policies (support to electric vehicles, charging infrastructure, regulatory landscape on automated driving, emissions and car usage in city centres) and consumer preferences (mobility patterns, attitude towards driving), adoption speed of electric and automated vehicles is likely to vary significantly across countries (PwC, 2020[35]; Deloitte, 2022[49]).

### Figure 11. Impact of the main trends in the automotive ecosystem on business models




Note: See paragraph 42 for a description of the main links between trends and their effects on business models.
Source: Authors.

## These trends could also deeply affect the market microstructure

First, these trends have an ambiguous impact on competition. On the one hand, the entry of new competitors could increase competition and foster business dynamics. On the other hand, the high level of investments needed and the growing role of data could lead to network externalities, higher economies of scale and lower competition. This could be reinforced by the evolution towards increasingly segmented markets.

Second, the advent of new technologies and the recent shortages could also affect global value chains. With the growing importance of software, customer experience and services, a larger share of value added could originate from OECD economies, partly reverting the previous trend. This could also be permitted by robotisation, which reduces the cost penalty of producing in high wage countries. However, the importance of semiconductors for vehicles, which has been recently brought to light by their global shortage, and raw materials for batteries is likely to continue growing in the future. Semiconductors and batteries are mostly produced in Asia, but the willingness of many governments to support their domestic production[12] could significantly affect the value chain.

The consequences of these trends on the automotive ecosystem will depend on the long term impact of the pandemic on mobility demand (e.g. teleworking, impact on public transportation and shared mobility services), which will be progressively unveiled as the pandemic hopefully ends. They also crucially depend on public policies (e.g. greenness of recovery plans, new infrastructure, support to innovation, standardisation of technologies, among others; see Section 8).

# 4 New technologies are profoundly affecting the landscape of innovation in the automotive ecosystem

This section uses patent data to analyse emerging trends which are likely to deeply affect the automotive ecosystem over the coming decades. It complements the value chain approach by identifying new actors that could become major players in the automotive ecosystem in the future and emerging trends in the market microstructure.

It confirms the rapidly growing importance of the green and digital transition in the ecosystem, with a tremendous increase in the number of patents related to autonomous vehicle and, to a lesser extent, to electric vehicle technologies. Hubs in the global automotive value chain, such as Japan, the United States and Germany, are also key players in automotive technologies, including in emerging technologies such as autonomous and electric vehicles or hydrogen technologies.

This section also highlights the increasing integration of the whole ecosystem, beyond large OEMs, with a growing role in the technological landscape for young firms, academic institutions and non-automotive firms (e.g. in the machinery and ICT sectors). Finally, it underlines the marked differences between the emerging technologies and the more traditional ones, as they rely on different knowledge bases. Nevertheless, co-patenting patterns suggest some complementarities between combustion, electric and hydrogen technologies.

## Even if the green and digital transitions significantly affect knowledge networks, the main automotive hubs remain the leaders in emerging technologies

### *Identifying patents and technologies linked to the automotive ecosystem*

The analysis presented in this paper leverages the OECD's STI MicroData Lab infrastructure. Patent data come from the Autumn 2021 version of the EPO Worldwide Patent Statistical Database (PATSTAT), covering filings of more than eighty patent offices worldwide. PATSTAT includes detailed information on patent fillings, including citations to other patents, references to the academic literature, and data on the names and residence of applicants and inventors (independent of the country in which the applications are actually filed). Squicciarini et al. (2013[50]) and Dernis and Squicciarini (2013[51]) provide additional details on the content of PATSTAT and discuss indicators of patent quality, scope, reach, and impact that can be constructed from the database.

An important methodological issue that arises when comparing patent filings across countries is the heterogeneous quality of patents. To address this issue, the sample in this analysis consists of patents belonging to so-called ‘IP5’ patent families. IP5 patent families are defined as sets of patent applications protecting the same invention filed in at least two intellectual property (IP) offices — with at least one application filed in one of the world’s top 5 patent offices (IP5): the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People’s Republic of China (CNIPA) and the United States Patent and Trademark Office (USPTO). [13]

To provide insights into the characteristics of patenting firms, the analysis uses Orbis data, published by Bureau Van Dijk. Orbis data includes information on firms, including industry of operation, date of incorporation, and ownership structure. A mapping between Orbis and Patstat is available through the STI MicroData Lab.[14]

This section focuses on 5 sets of patents:

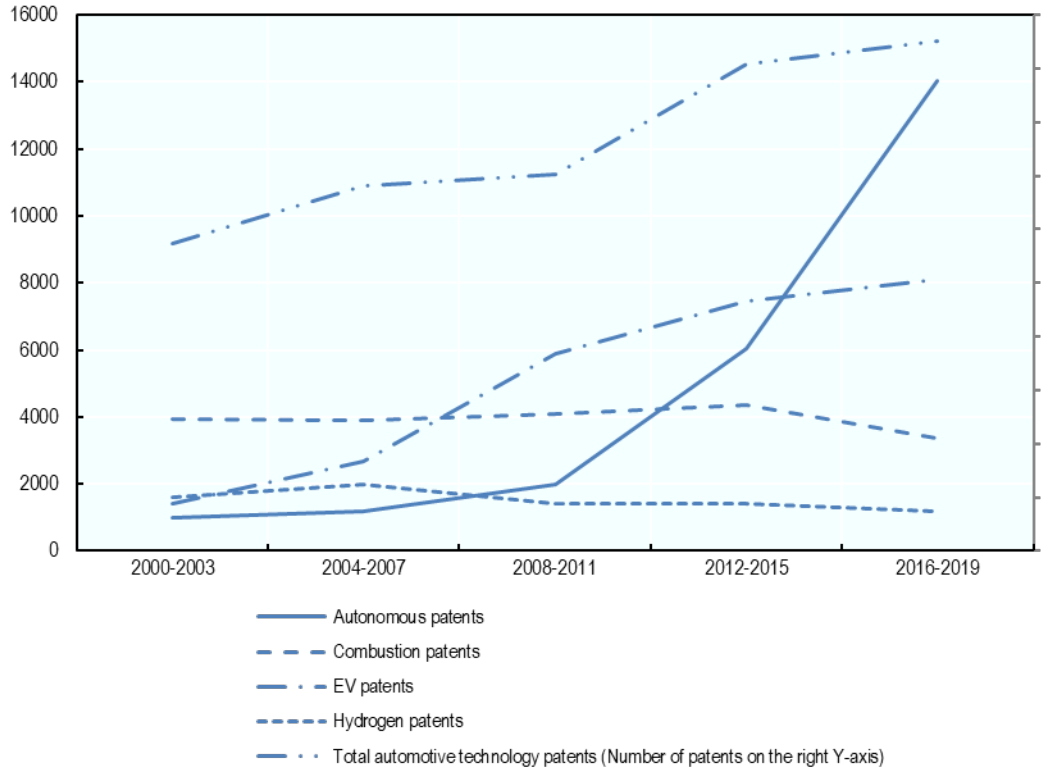
- The first set of patents correspond to technologies deemed relevant for the automotive ecosystem (total automotive technology patents). Patents in this category are identified using a concordance table between the international patent classification (organised by technology) and a classification of economic activities (Van Looy, Vereyen and Schmoch, 2014[52]). This concordance table is defined by associating patents with the economic sector of the final use of the invention. For the purpose of this analysis, the sample consists of patents associated with ISIC Rev.4 Divisions 29 (Manufacture of motor vehicles, trailers and semi-trailers) and 30 (Other transport equipment n.e.c.). The latter, which includes shipbuilding, manufacture of railway rolling stock and aerospace and military vehicles, also faces challenges related to autonomous driving and the transition towards carbon neutrality (OECD, 2020[53]). A detailed description of the technologies covered in this first set of patents is presented in Annex A.
- The four other sets focus on selected technologies: internal combustion engines (used as a benchmark) and three emerging technologies – hydrogen vehicles, electric vehicles and autonomous vehicle technologies.[15]
  - Internal combustion engine technologies are identified following the methodology proposed by Borgstedt et al. (2017[54]). Patents in this technology are identified using the International Patent Classification (IPC) classes F02B, F02D, F02F, F02M, F02N and F02P. Additionally, patents in this set must include the words *vehicle*, *car*, or *automobile* in their title or abstract.
  - Transportation-related hydrogen patents are identified using the Cooperative Patent Classification (CPC) and include the application of hydrogen technology to transportation (CPC code Y02T 90/40) and fuel cells (CPC code Y02E 60/50).
  - Electric vehicle patents are identified by adapting the methodology proposed by Borgstedt et al. (2017[54]) using CPC classes Y02T10/6, Y02T10/, Y02T90/14, Y02T90/16, and Y02T90/12. Additionally, patents in this set must include the words *vehicle*, *car*, or *automobile* in their title or abstract. This set includes patents linked to batteries for electric vehicles as soon as they include one of the keywords related to automotive.
  - Autonomous vehicle patents are identified through a combination of IPC codes and keywords, following the method developed by Zehtabchi (2019[55]).[16]

### *Patent analysis confirms the growing importance of the green and digital transitions in automotive innovation*

Though the growth rate has slowed down since 2010, the number of annual patent applications for EV-related technologies has been greater than patent applications for combustion engine-related technologies since 2007 (Figure 12).[17] In comparison, however, the pace of innovation is much lower in transport-related hydrogen technologies (including fuel cells), which has surprisingly decreased since 2007, perhaps following an emerging consensus that battery-powered electric vehicles will outperform hydrogen cars for light passenger vehicles, at least in the short to medium run (Cammeraat, Dechezleprêtre and Lalanne, 2022[30]). The number of patent applications for autonomous vehicle-related technologies has also increased dramatically in the last decade, surpassing both the number of patent applications for combustion engines and EV technologies.

Importantly, the growth in EV-related and autonomous vehicle patents is not a mere reflection of the growth of patenting in automotive technologies in general. A steady increase in total patents related to automotive technologies has occurred in the last two decades (Figure 12), but this increase (+50% since 2000) is much smaller than in EV (+500%) and autonomous vehicles (+1400%).

**Figure 12. Patent filings in total automotive technologies, hydrogen, autonomous vehicles, combustion engines and electric vehicles, 2000-2019**



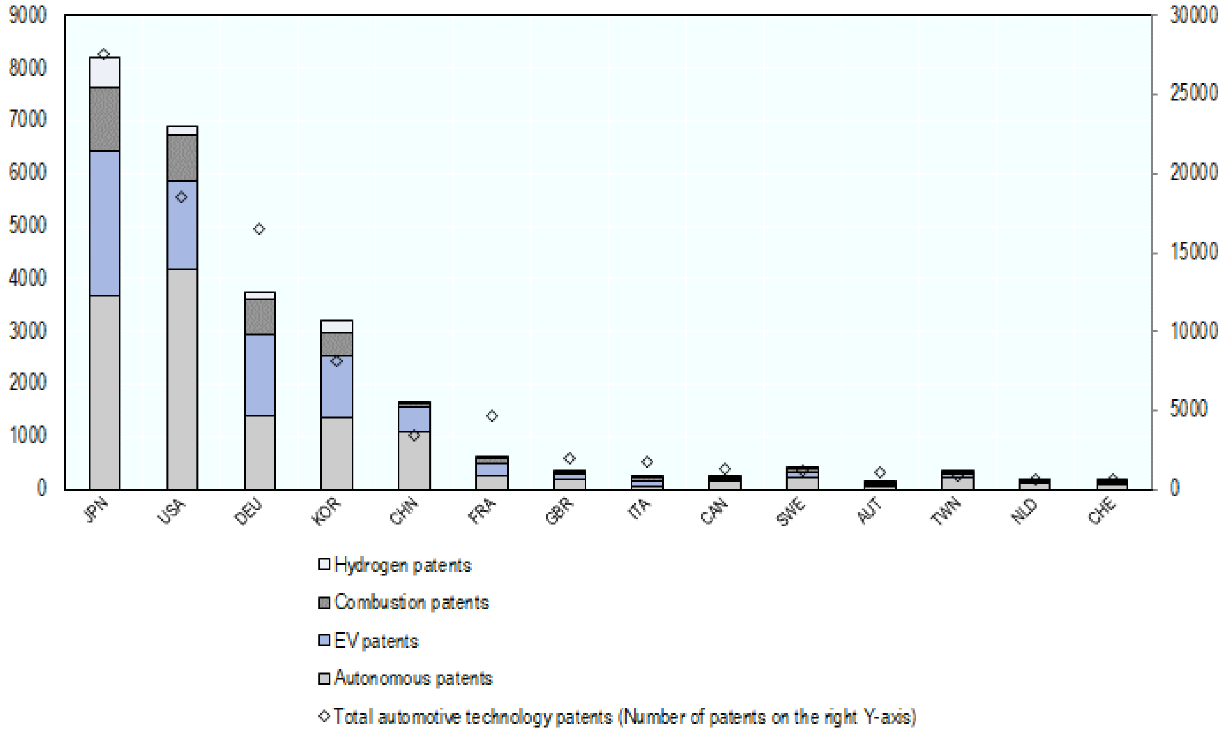

Note: Patent families are only assigned to one of the four technologies. If a patent family can be linked to multiple technologies, it is categorised based on the following order of priority: Hydrogen, Autonomous, Electric, and Combustion. To be included in the sample, the patent family must be filed in at least two patent offices, one of which among the IP5 offices (US Patent and Trademark Office, the European Patent Office, the Japan Patent Office, the Korean Intellectual Property Office, and the National Intellectual Property Administration in China). The methodology is described in detail in Annex A.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022.

### *Several European countries and Japan have a relative technology advantage in automotive technologies*

Japan, the United States, Germany and Korea have filed the highest number of automotive patents over the last years (Figure 13). The first two hold a clear dominance in autonomous patents; Germany has a slight dominance in EV patents and in Korea autonomous and EV patents have almost the same importance. Moreover, autonomous patents also dominate in other economies such as Canada or

Sweden. Hydrogen patents are still a nascent type of technology, as represented by their low frequency, with Japan being the economy with the highest number of innovations in this technology.

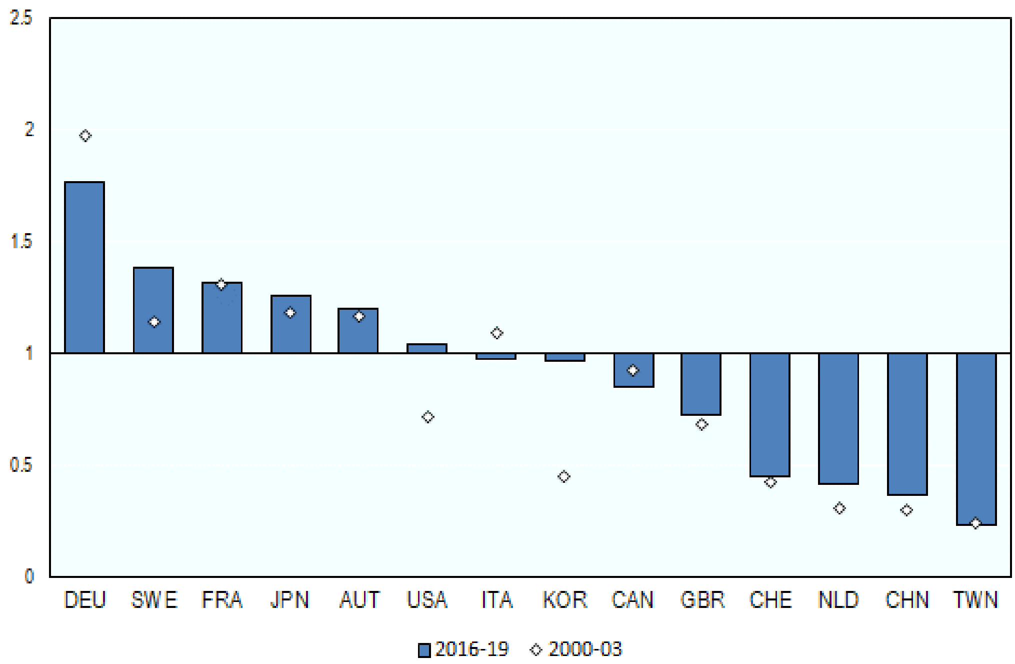
## Figure 13. Patent filings by economy in total automotive technologies, hydrogen, autonomous vehicles, combustion engines and electric vehicles, 2016-2019




Note: Same as Figure 12. The figure shows the 14 economies with more than 500 automotive technology patents over 2016-2019. The methodology is described in detail in Annex A. Patents in one of the four technologies (combustion, electric, hydrogen and autonomous) are not necessarily included in the 'total automotive technology' patents due to different selection criteria, and vice versa.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022.

A high number of patents in automotive technologies can signal either overall innovation performance (which depends on the size of the economy) or a focus on automotive technologies. To disentangle these two explanations, Figure 14 shows the Relative Technology Advantage (RTA) in selected technologies. This index is obtained by dividing each economy's share of patents in a technology with the global share of patents in the same technology. For example, if automotive patents represent 2% of all patents filed by inventors based in Germany, but 1% of all patents filed globally, then Germany would have an RTA of 2.

## Figure 14. Relative technology advantage in total automotive technologies

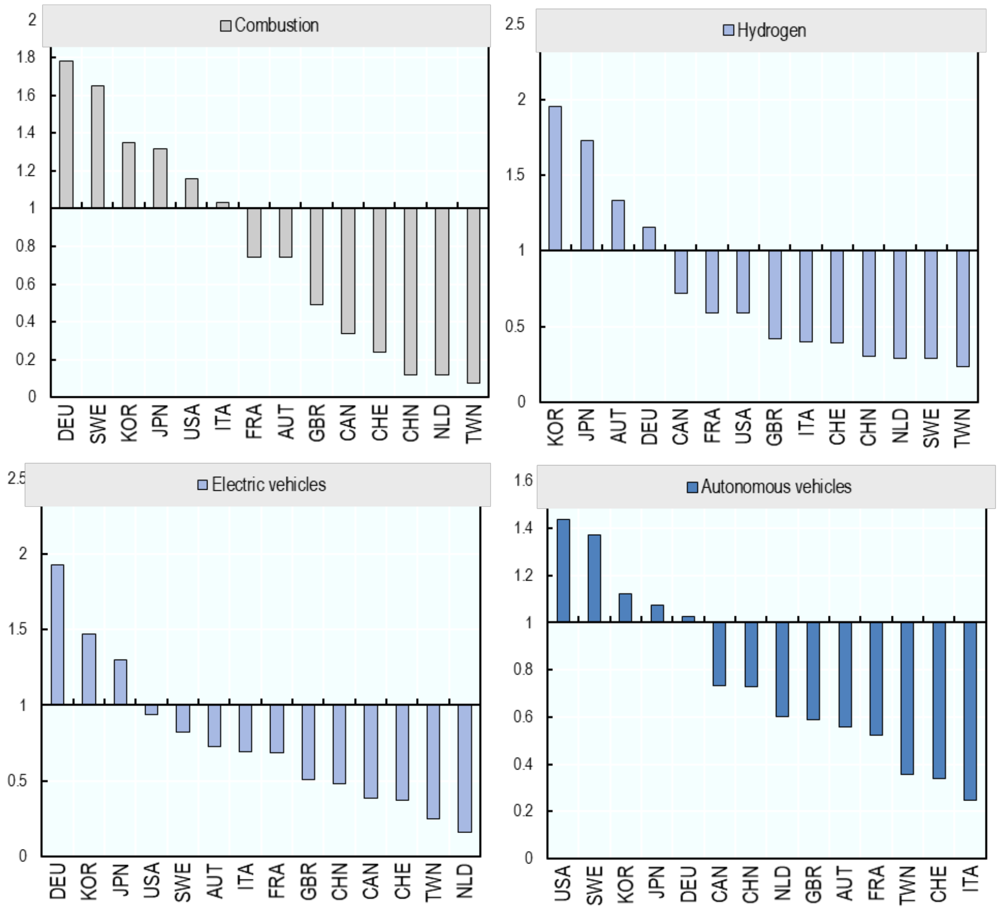



Note: Same as Figure 12. The methodology is described in detail in Annex A. This Relative Technology Advantage is obtained by dividing each economy's share of patents in a technology with the global share of patents in the same technology.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022.

Several European economies (Germany, Sweden, France and Austria) and Japan have a strong relative technology advantage in automotive, whereas China and Korea, but also the Netherlands and Switzerland, tend to be under-specialised in these technologies. The United States are close to the average, but with a slight relative advantage in automotive technologies.

In addition, RTAs vary significantly by technology (Figure 15). For Germany, Korea and Japan, the RTA is driven by a strong specialisation in combustion, hydrogen, and electric vehicles and, to a lesser extent, autonomous vehicle technologies. The United States and Sweden have a relative advantage in combustion engines and autonomous vehicle technologies, but a disadvantage in 'green' technologies (i.e. hydrogen and electric engines). France, Italy and the United Kingdom have a disadvantage in the three emerging technologies.

## Figure 15. Relative technology advantage in selected technologies, 2016-2019



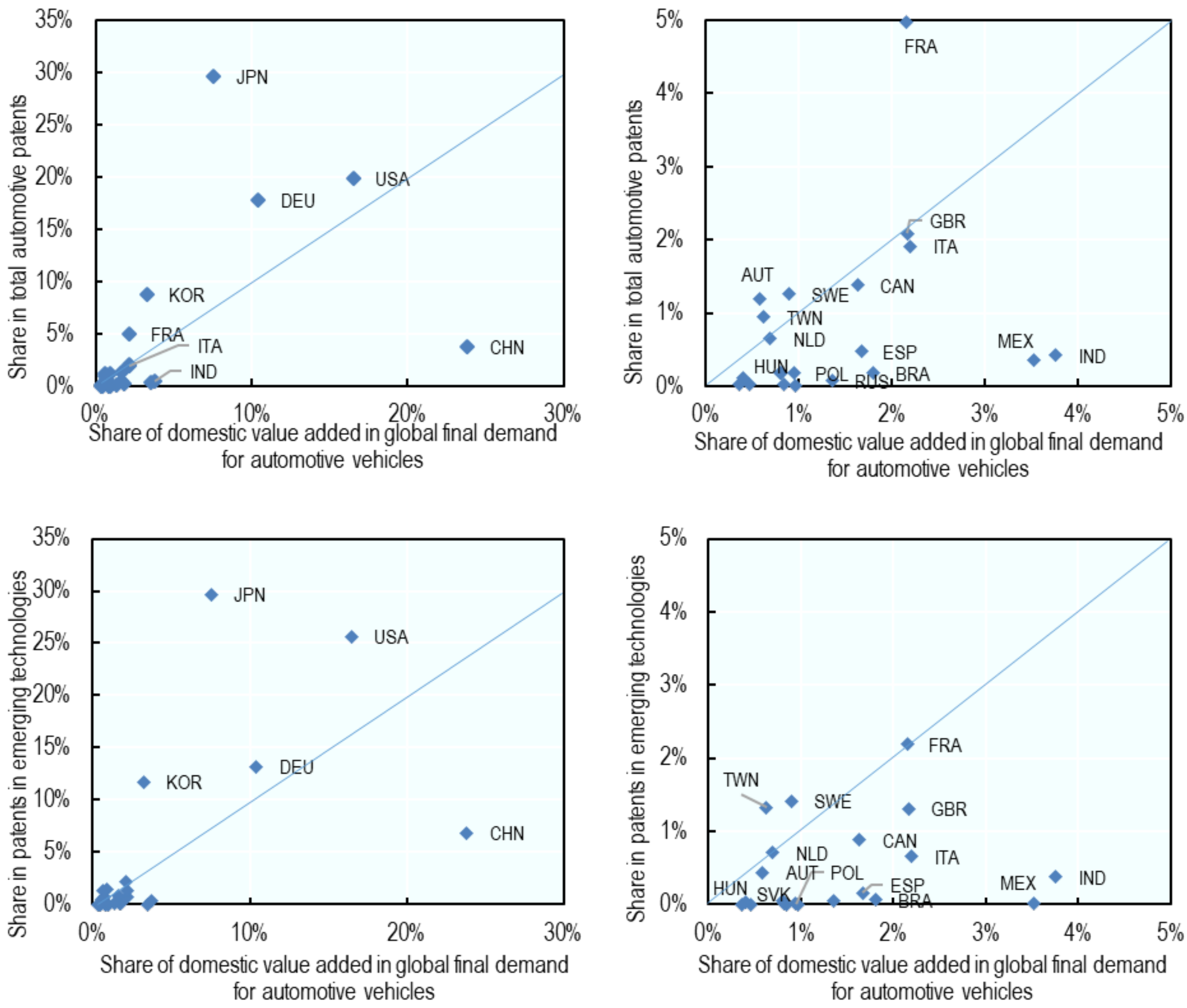

Note: Same as Figure 12. The methodology is described in detail in Annex A. This Relative Technology Advantage is obtained by dividing each economy's share of patents in a technology with the global share of patents in the same technology.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022.

### *The most important hubs in the automotive value chain are also the countries filing more patents, including on emerging automotive technologies*

Economies participating in the automotive value chain are also the ones patenting in automotive patents, including on emerging technologies (Figure 16).

### Figure 16. Correlation between automotive value chain participation and patents in 2018

Share of domestic value added in global final demand for automotive vehicles, by economy, against the share of total automotive patents (top panels) and the share of patents in emerging technologies (bottom panels). All economies (left panels) and zoom on the smaller ones (right panels).




Note: The right-hand side figures zoom in on the bottom left part of the left-hand side ones.The share of domestic value added in global final demand for automotive vehicles is measured in 2018 (see Figure 8). The share in total automotive patents and emerging automotive technologies are for 2016-2019. Emerging automotive technologies consist of autonomous vehicles, electric vehicles and hydrogen (see also Figure 12). The 45 degree line is represented in blue.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022; OECD Inter-Country Input-Output Database, http://oe.cd/icio; OECD calculations.

Patents are not only correlated with the participation in automotive GVCs, but also with the centrality[18] of automotive sectors. Holding participation in automotive GVCs constant, increasing the number of patents in total automotive technologies by one standard deviation increases the centrality of the automotive sector by 0.4 standard deviation.

Large emerging economies, but also Central and Eastern European countries, although they play a significant role in GVCs, represent only a minor share in patents and have a low centrality compared to their weight in value added. Economies that have a low weight in emerging automotive technologies

(Figure 16), such as Spain of Italy for instance, might also occupy a more peripheric place in GVCs in the future.

## At the microeconomic level, the twin transitions significantly affect knowledge networks and allow the entry of new players

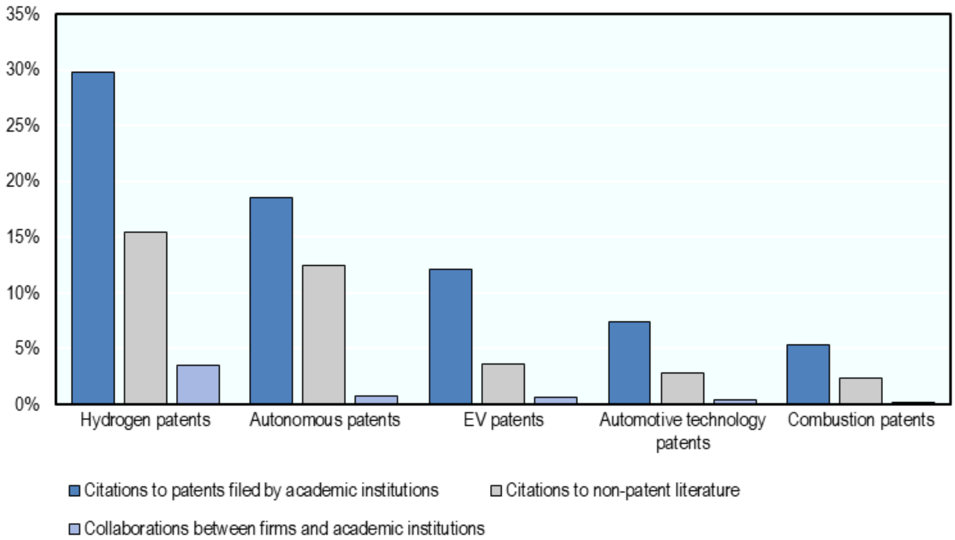
### *Emerging technologies strengthen the role of young firms and academic institutions*

Patent data can be used to measure the degree of collaboration between private firms and academic research for the different automotive technologies. Three indicators are presented below: the share of inventions citing university patents (thus relying on previous patents filed by academic institutions); the share of inventions citing academic publications (thus directly relying on academic research) and the share of patent applications jointly filed by firms and academic institutions.

Figure 17 shows that patents in emerging technologies (particularly hydrogen, and to a lesser extent autonomous vehicles and electric vehicles) present a higher share of citations to university patents and to the academic literature relative to patents in traditional combustion technologies. This indicates the key role of universities and research institutes for the development of these technologies. This result is confirmed when looking at the share of patents filed in collaboration between firms and academic institutions[19]. For the three measures, the ranking of technologies is exactly the same.

## Figure 17. Emerging technologies are strongly linked with universities and scientific research

Share of citations to patents filed by academic institutions, share of citations to academic literature and share of collaborative patents between firms and academic institutions for the different type of automotive technologies, 2000-2019

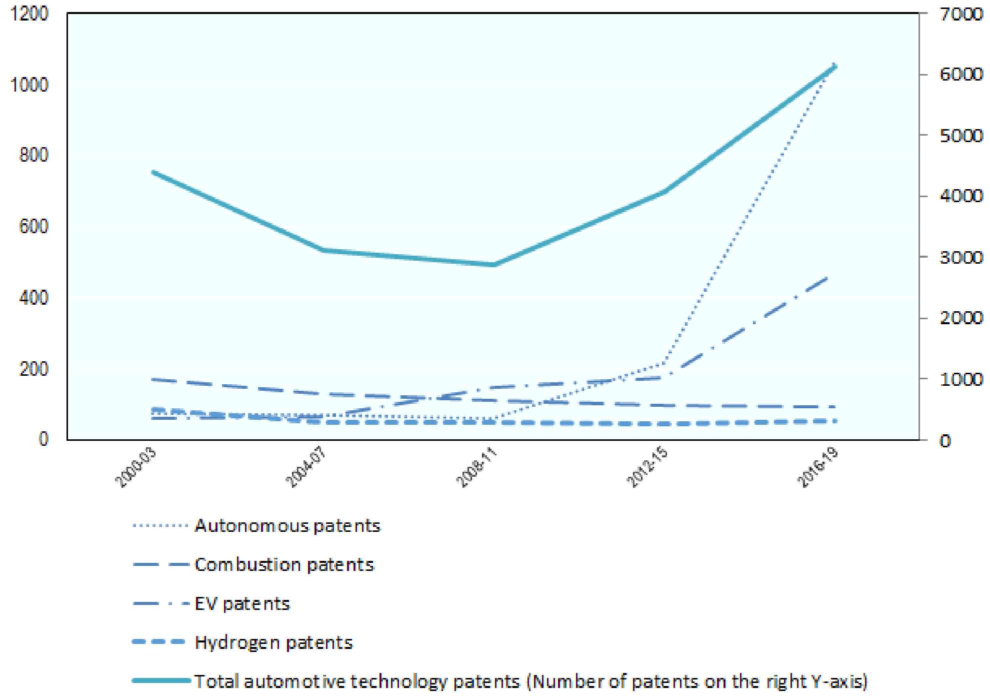



Note: A collaboration is defined as a patent family with at least two applicants, one of them being a firm and another a non-firm entity (e.g universities, governments, hospitals, etc.). Patents filed by academic institutions only include patents for which the type of applicant (individual, company, government entity, etc…) is identified. A patent is labelled as citing an academic patent if at least one application in the patent family cited a patent filed by an academic institution. A patent family is labelled as citing the academic (non-patent) literature if at least one patent in the patent family made a citation to a Serial / Journal / Periodical citation, a chemical abstract citation, or a biological abstract citation. When labelling a patent family as citing the non-patent literature, the sample is restricted to those patent families that have at least one patent application at the EPO, USPTO, or WIPO (PCT applications). This restriction is necessary as non-patent literature citations are only available for patents filed in one of these three offices.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022.

Young firms (less than 5 years old) play an important role in the development of emerging technologies. Specifically, young firms have significantly contributed to the growth of innovation in autonomous technologies – and to a lesser extent in EV technologies – in the last decades (Figure 18). While most innovation activity still comes from old firms (13 343 total patents in automotive technologies vs 1 308 for young firms in the period 2016-19), innovation coming from young firms has increased at a faster rate for autonomous vehicle and electric vehicles technologies than innovation coming from old firms. This could induce future changes in the composition of the industry in these technologies, and in the automotive ecosystem in general.

## Figure 18. Young firms are increasingly innovating in automotive technologies, particularly in emerging technologies

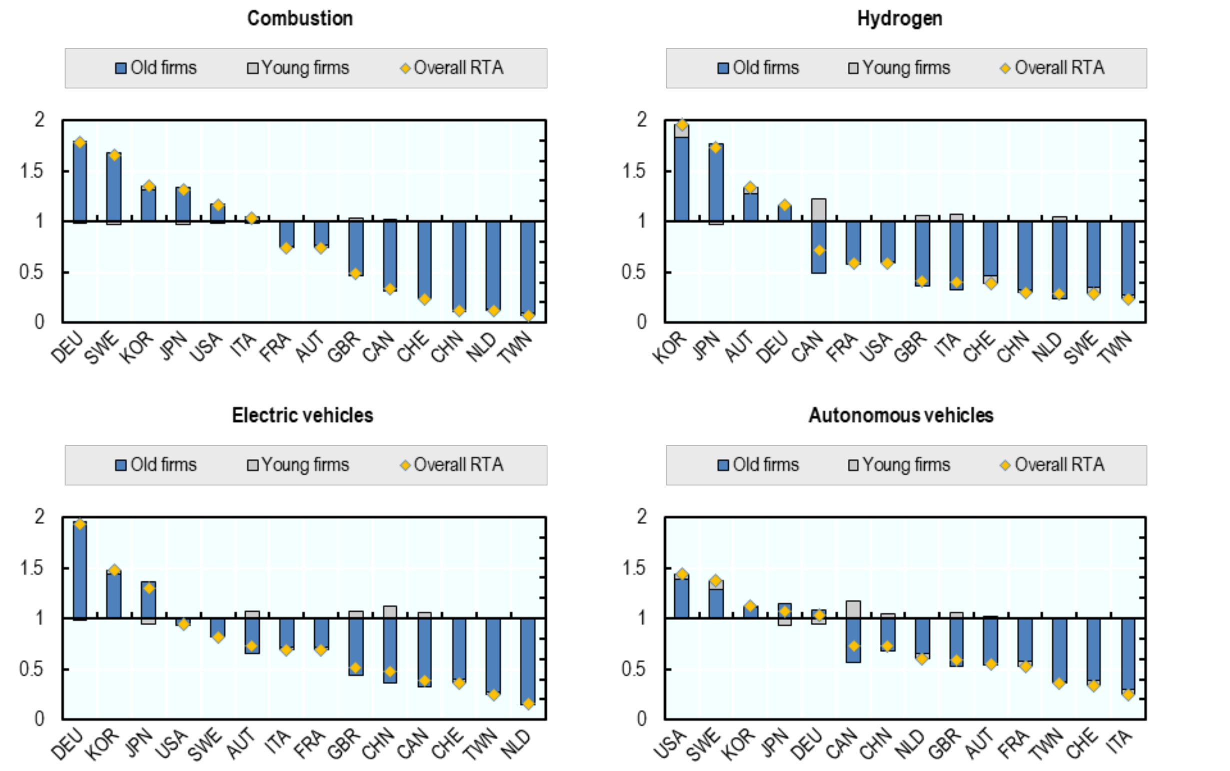
Number of total automotive technology patents and patents by technology filed by young firms.




Note: Same as Figure 12. The methodology is described in detail in Annex A.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022. And ORBIS, OECD calculations.

Even if RTAs are mainly driven by old firms (Figure 19), young firms significantly contribute to RTAs across all categories in countries like the United Kingdom and Canada, although their contribution is more significant for emerging technologies. In European countries, young firms positively contribute to RTAs for specific technologies (e.g. hydrogen in Italy and the Netherlands, electric engines in Austria or autonomous vehicles in Sweden). Young firms positively contribute to the RTA in a given technology and country if the share of this technology in patents filed by young firms in this country is higher than the share of this technology in total patents.

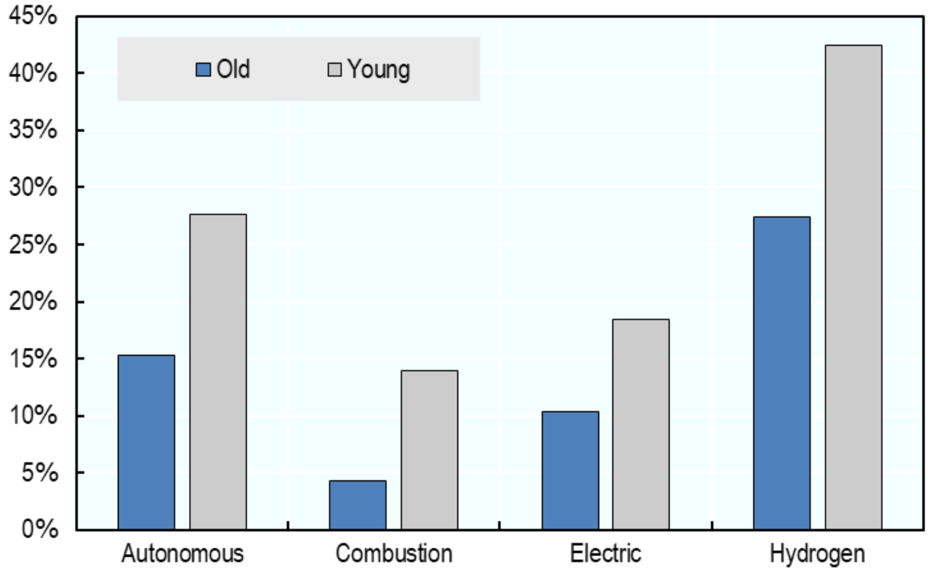
## Figure 19. Relative technology advantage in selected technologies, 2016-2019, contribution by firm age category




Note: Same as Figure 12. The methodology is described in detail in Annex A. The Relative Technology Advantage is obtained by dividing each economy's share of patents in a technology with the global share of patents in the same technology. The contribution of each age category $x$ in economy $c$ and technology $i$ is obtained using the following formula: $Contrib\_RTA_{x,i,c} = \left(\frac{\#P_{x,i,c}/\#P_{x,c}}{\#P_i/\#P} - 1\right) * \frac{\#P_{x,c}}{\#P_c}$, where $\#P$ denotes the fractional number of patents.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022.

These two trends – the growing role of young firms and the importance of academic knowledge for emerging technologies – are interrelated as young firms significantly cite more academic patents, and this pattern is consistent across technologies (Figure 20). This is consistent with empirical evidence showing that young innovative firms tend to locate themselves in close proximity to universities and research centres (O'Shea, Chugh and Allen, 2008[56]), including in the form of academic spin-offs (Rammer, Kinne and Blind, 2020[57]), and that start-up companies play an important role to commercialise academic patents (Meyer, 2006[58]).

## Figure 20. Share of patents citing patents filed by academic institutions, by firm age and technology

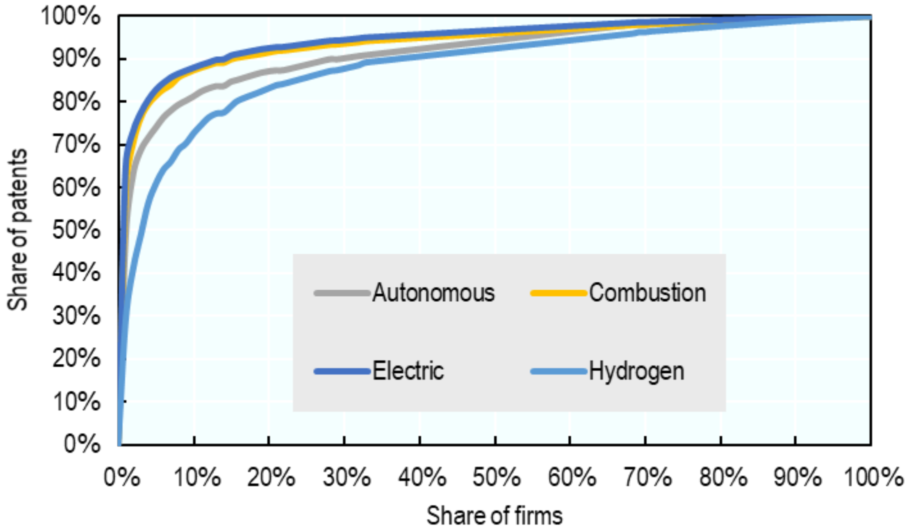



Note: Same as Figure 12. The methodology is described in detail in Annex A. A patent is labelled as citing an academic patent if at least one application in the patent family cited a patent filed by an academic institution.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022. And ORBIS, OECD calculations.

Old firms act as technology integrators, whereas young firms seem to specialise on specific technology blocks. For instance, conjoint control of vehicule subunits (IPC subclass B60W) represents 11% of autonomous vehicle patents filed by old firms, but only 5% of those filed by young firms. On the contrary, sensors (IPC subclass B60R) represent 9% of patents filed by young firms, and only 7% of those filed by old firms. Similarly, conjoint control of vehicule subunits (IPC subclass B60W) represents 16% of electric vehicle patents filed by old firms, but only 4% of those filed by young firms. Propulsion of electric vehicles (IPC subclass B60L) represent 29% of patents filed by young firms, and only 23% of those filed by old firms.

More generally, patenting is less concentrated in hydrogen and autonomous technologies than in combustion engine technologies (Figure 21). For electric vehicles, the concentration in patent filing is similar to combustion engines.

## Figure 21. Concentration of patents for selected technologies

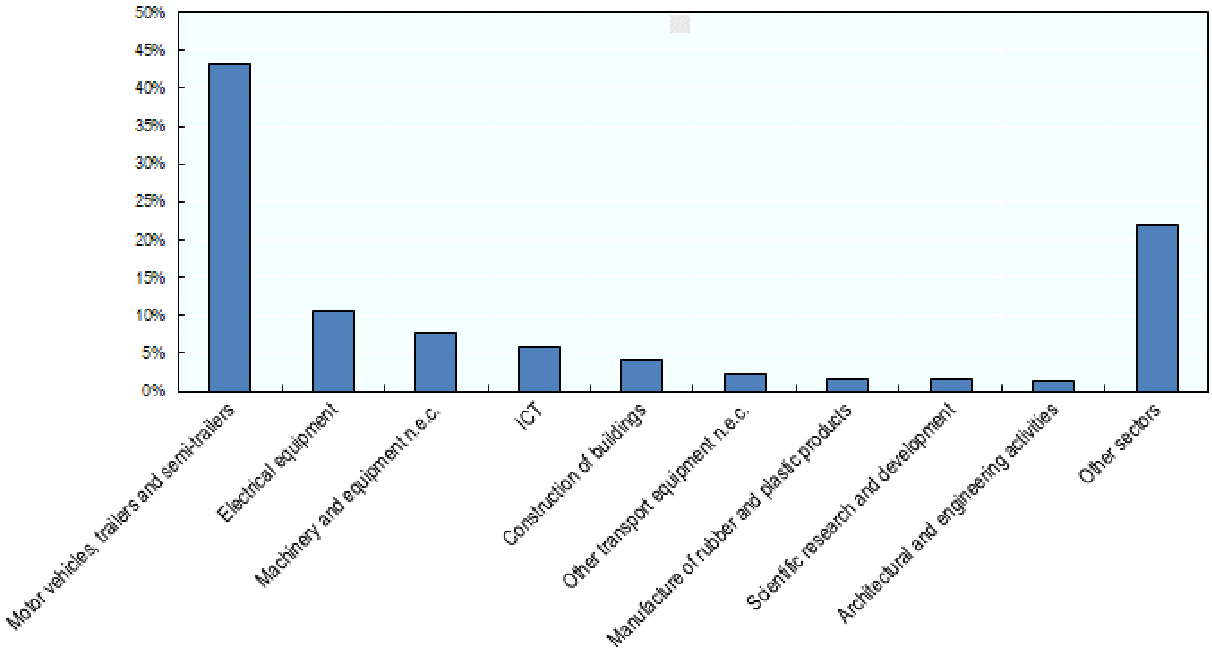



Note: Same as Figure 12. The methodology is described in detail in Annex A. 10% of firms filed 73% of patents in hydrogen technologies and 88% of firms in electric engine technologies.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022. And ORBIS, OECD calculations.

### *Besides car producers, manufacturers of electrical and machinery equipment and ICT firms are important sources of automotive innovations*

Figure 22 shows that an important share of automotive technology patents are filed by firms outside the automotive sector, notably by firms from the 'Manufacture of electrical equipment' sector (ISIC Rev.4 Division 27), the 'Manufacture of machinery and equipment n.e.c.' sector (ISIC Rev.4 Division 28) and the ICT sectors (ISIC Rev.4 Divisions 26, 58, 62 and 63).

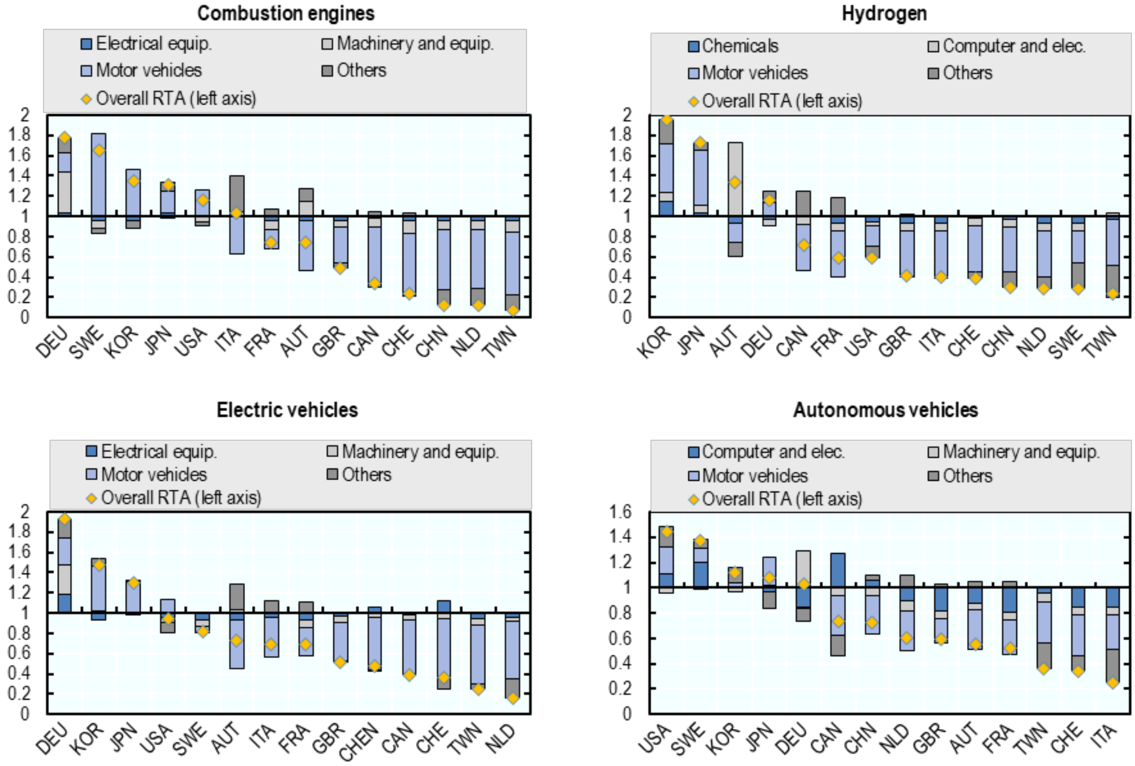
## Figure 22. Sectors filing patents in total automotive technologies over the period 2000-2019




Note: Same as Figure 12. The methodology is described in detail in Annex A. "ICT" refers to firms in sectors ISIC Rev.4 Divisions 26, 58, 62 and 63.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022. And ORBIS, OECD calculations.

Sectoral contributions to RTAs display interesting patterns (Figure 23). First, the machinery and equipment sector is a significant contributor to RTAs in Germany across all technologies. Second, the computer and electronics sector significantly drives the RTAs in autonomous vehicle technologies.

## Figure 23. Relative technology advantage in selected technologies, 2016-2019, contribution by sector

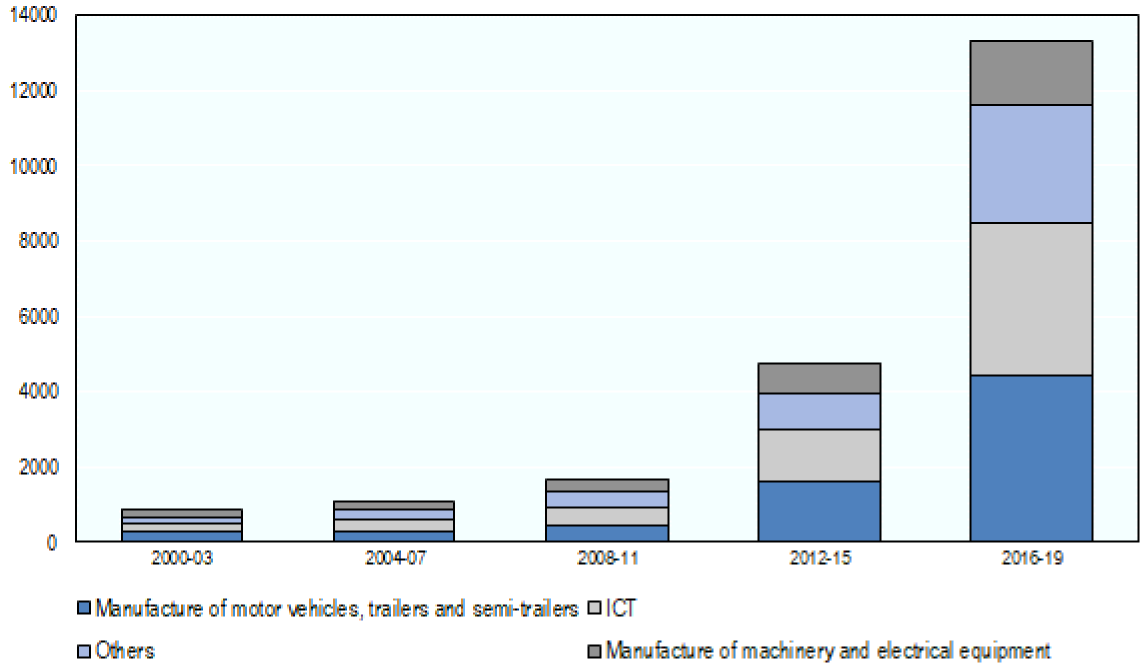



Note: Same as Figure 12. The methodology is described in detail in Annex A. The Relative Technology Advantage is obtained by dividing each economy's share of patents in a technology with the global share of patents in the same technology. The contribution of each sector $x$ in economy $c$ and technology $i$ is obtained using the following formula: $Contrib\_RTA_{x,i,c} = \left( \frac{\#P_{x,i,c}/\#P_{x,c}}{\#P_i/\#P} - 1 \right) * \frac{\#P_{x,c}}{\#P_c}$ where $\#P$ denotes the fractional number of patents.

Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022.

Automotive firms indeed compete with ICT firms for the development of autonomous vehicles (Figure 24). Nevertheless, the share of autonomous vehicle-related patent applications filed by automotive firms has increased over the last decade, whereas this share remained stable for ICT firms.

## Figure 24. Number of patents on autonomous vehicles by industry of filing companies

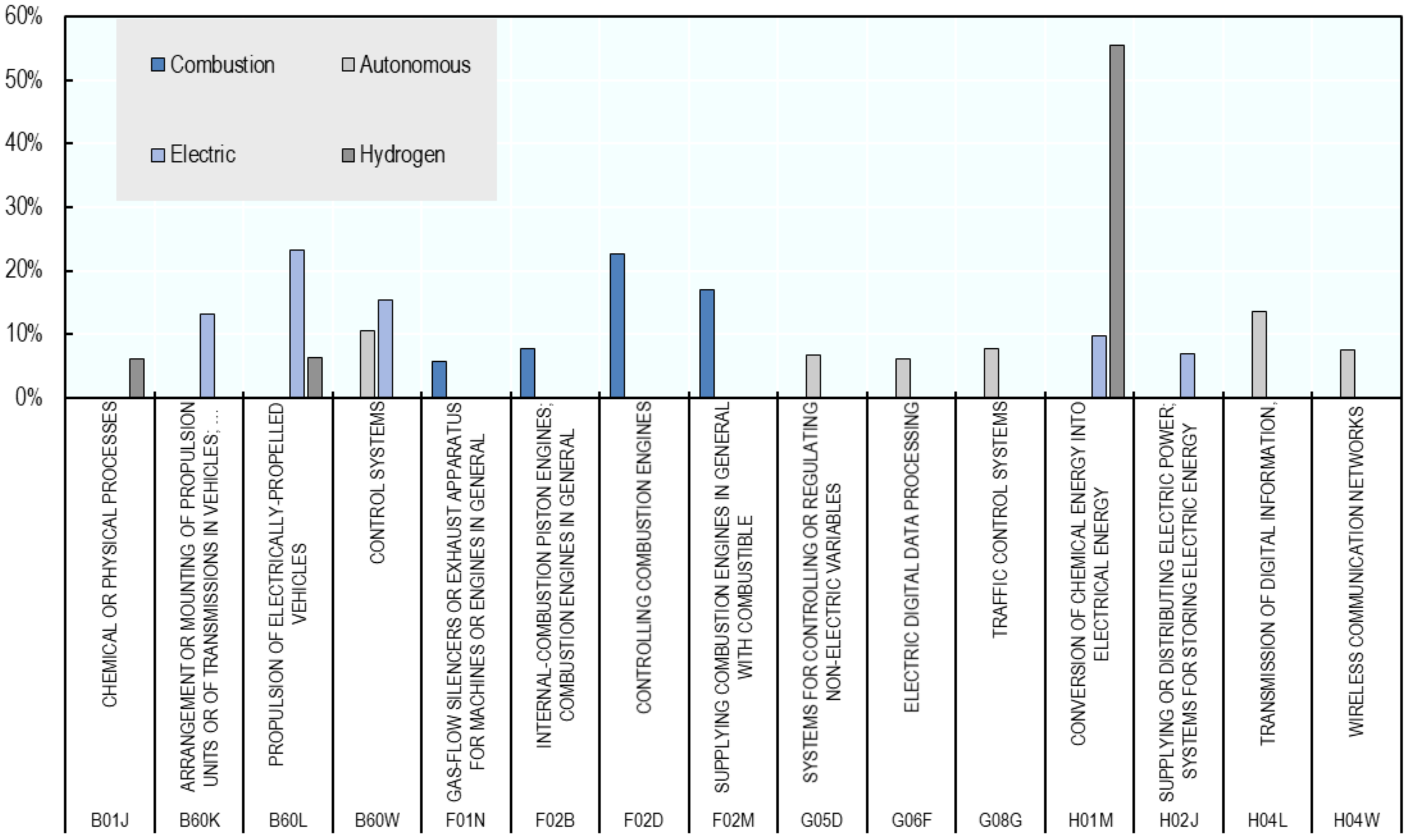



Note: Same as Figure 12. The methodology is described in detail in Annex A.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022. And ORBIS, OECD calculations.

### *Emerging technologies consist of different core technologies*

Emerging automotive technologies are clearly different from combustion engine technologies in terms of relevant technical knowledge. This is apparent from Figure 25, which shows the share of patents by IPC subclass in each of the four automotive-related technologies. The relevant subclasses markedly differ across technologies. For instance, combustion engines patents are concentrated in mechanical engineering (IPC section F), whereas other technologies do not rely on this IPC section. Electric and hydrogen technologies instead rely on electric propulsion and chemical processes technologies. Autonomous vehicle technologies rest on automated controls and electric communication techniques.

## Figure 25. Share of patents by IPC subclass for selected technologies




Note: Same as Figure 12. The methodology is described in detail in Annex A.This figure only displays IPC subclasses with at least 5% of patents of a given technology. The difference is not entirely driven by the definition of the technologies, as only the definition of combustion engine patents rely on IPC classes. In addition, this figure relies a fractional count of subclasses (i.e. a patent related to two subclasses counts for 0.5 in these two subclasses).
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022.

The distance between technologies can be measured using the Jaffe correlation, which measures the correlation between the distribution of patents across IPC codes (Jaffe, 1986[59]).The closest technologies are electric and hydrogen vehicles, followed by electric and combustion technologies (Table 1). However, correlation coefficients are low, confirming that emerging technologies in the automotive sector correspond to very different technical areas compared with the incumbent (combustion engines) technology.

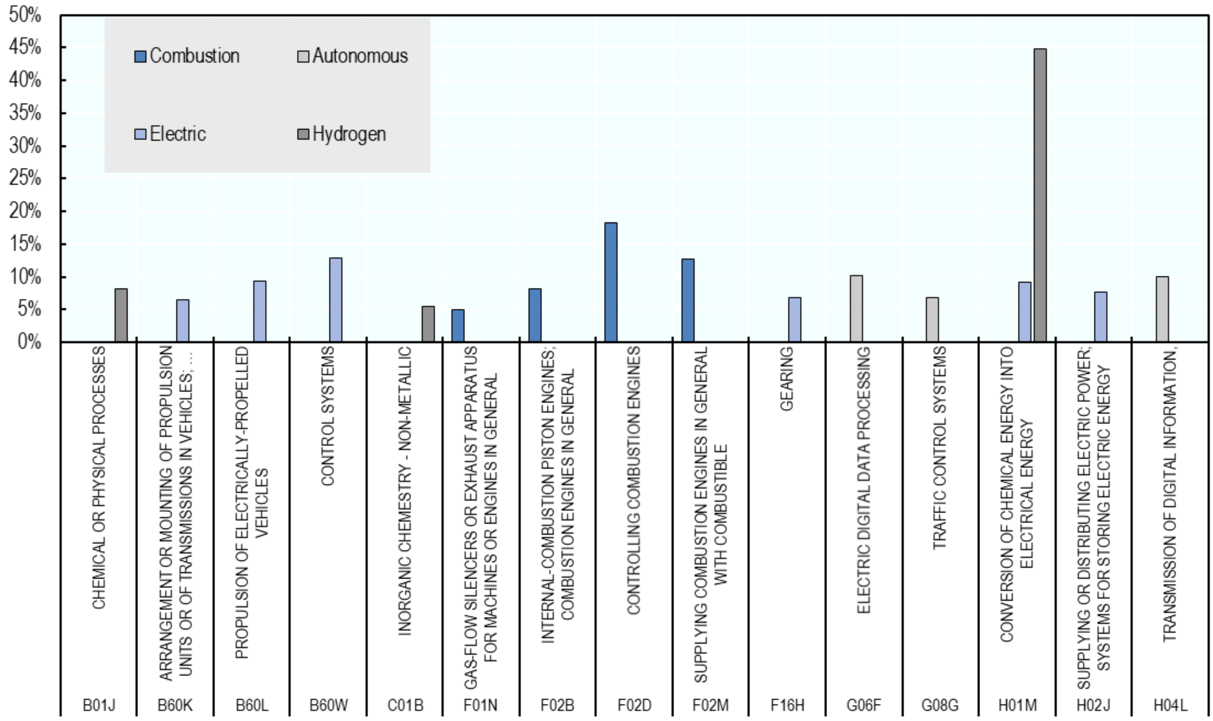
## Table 1. Jaffe correlation across selected technologies

| | Autonomous | Combustion | Electric | Hydrogen |
|---|---|---|---|---|
| Autonomous | 1.00 | 0.04 | 0.06 | 0.01 |
| Combustion | | 1.00 | 0.13 | 0.01 |
| Electric | | | 1.00 | 0.16 |
| Hydrogen | | | | 1.00 |

Note: The Jaffe correlation corresponds to the correlation between vectors composed of share of patents by IPC subgroup (i.e. 8-digit).
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022.

Emerging technologies do not only consist of different technologies but also rely on different underlying technologies. Figure 26 shows the distribution of IPC subclasses of patents *cited* by patents in the four automotive-related technologies, excluding citations to patents belonging to the same technology (e.g. citations from an autonomous patent to another autonomous patent).[20] The analysis of cited patents points to the technologies underlying the current wave of innovation.

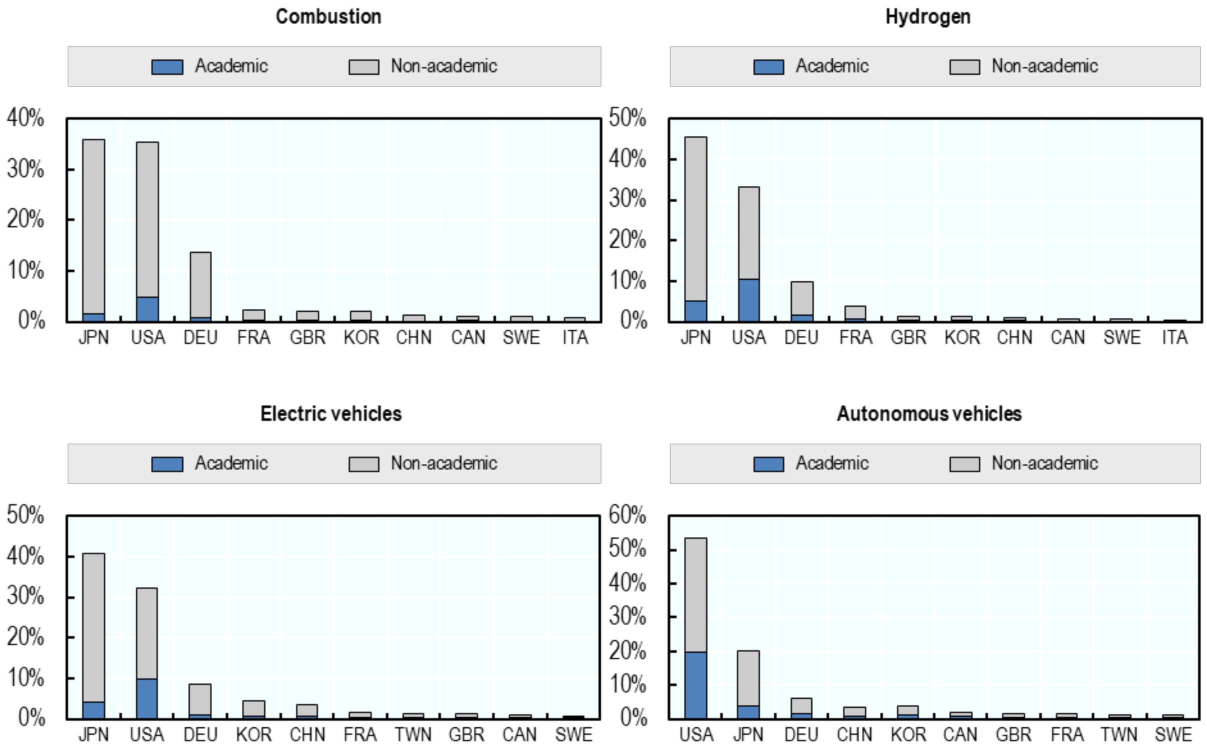
## Figure 26. Distribution of citations across IPC subclasses, for selected technologies




Note: Same as Figure 12. The methodology is described in detail in Annex A. This figure only displays IPC subclasses with at least 5% of citations from a given technology. It excludes citations to patents belonging to the same technology (e.g. citations from an autonomous patent to another autonomous patent).
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022.

For the four selected technologies, citations are highly concentrated on US and Japanese patents, and to a lesser extent on German patents (Figure 27). As these countries are also the main patenters in those technologies, this pattern could be driven by a 'domestic bias', whereby patents are more likely to cite patents from entities located in the same economy. However, the pattern in Figure 27 remains the same when restricting to cross-border citations.

## Figure 27. Distribution of citations by origin of the cited patents, for selected technologies




Note: Same as Figure 12. The methodology is described in detail in Annex A. This figure excludes citations to patents belonging to the same technology (e.g. citations from an autonomous patent to another autonomous patent).
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022.

Although most citations are to non-academic patents (i.e., patents filed by private companies), the United States and Japan also dominate in terms of citations to academic patents (i.e. patents filed by universities and public research organisations) in the four selected technologies (Figure 27).Citations to US academic patents are consistently more frequent than citations to Japanese academic patents across the four selected technologies.

### *There are however complementarities between old and emerging technologies*

Most firms are specialised in a small number of technologies, especially young firms which rarely patent in more than one of the four selected technologies (Table 2).

However, firms filing patents in all four technologies hold the majority of automotive-related patents (Table 2). These firms tend to be larger as measured by the size of their patent portfolio (see also Box 3).

## Table 2. Distribution of firms and patents across the number of selected technologies in which firms patent

| Number of technologies | Young firms | | | Old firms | | | All firms | | |
|---|---|---|---|---|---|---|---|---|---|
| | Firms | Portfolio size | Share of patents | Firms | Portfolio size | Share of patents | Firms | Portfolio size | Share of patents |
| 1 | 1602 | 1 | 86% | 5343 | 2 | 10% | 6945 | 2 | 12% |
| 2 | 41 | 5 | 11% | 916 | 7 | 8% | 957 | 7 | 8% |
| 3 | 6 | 9 | 3% | 375 | 25 | 13% | 381 | 24 | 12% |
| 4 | 0 | 0 | 0% | 196 | 263 | 69% | 196 | 262 | 67% |

Note: Same as Figure 12. The methodology is described in detail in Annex A. For this table only, if firms patent both when young and old, they are considered old.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022.

The pattern of co-patenting across technologies highlights the complementarity between electric and hydrogen technologies on the one hand and combustion and hydrogen technologies on the other hand. Among firms that patent exactly in two technologies, the frequency of the electric-hydrogen combination is more than twice what would be expected if technologies were randomly selected by firms. Similarly, the frequency of the combustion-hydrogen combination is close to twice its expectation under random selection of technologies. On the contrary, the frequency of the autonomous-combustion combination is reduced by half. For firms that patent in exactly three technologies, the combustion-electric-hydrogen combination is 82% more frequent than predicted by a random selection of technologies. The pattern of co-patenting between combustion, electric and hydrogen technologies broadly confirms the analysis on IPC subgroups in Table 1.

### Box 3. The profile of firms in the automotive ecosystem - An exploratory clustering analysis

This box performs a clustering analysis at the firm level to identify common patterns on the patenting behaviour across firms. The results distinguish between three groups of patenters: very large firms being active in all the technologies; firms with a large patent portfolio that are mainly active in automotive technologies and firms with a smaller patent portfolio, which is more concentrated on emerging technologies. Although the last two categories mainly contain large and old firms, the size and age composition of the last two groups is much more diverse than the first group. In addition, most firms from the third group are not in the automotive sector.

#### Methodology

The clustering analysis is performed using the Orbis and Patstat data on the set of firms that are active in 2018 and either belong to the automotive sector or patent in one the five patent sets described earlier (autonomous, combustion, electric, hydrogen or total automotive).

The clustering is performed on the following set of variables: number of patents in each patent set (total automotive technologies, autonomous vehicles, combustion engines, electric vehicles, hydrogen), logarithm of employment, age, foreign ownership dummy, sector dummies at the 2-digit level. Robustness analysis has been carried out by removing the sector dummies or by using sector dummies at the 4-digit level, without affecting significantly the results. The inclusion of other variables such as tangible and intangible fixed capital or value added significantly reduces the firm sample without affecting the main messages of this analysis.

A k-means algorithm (Hastie, Tibshirani and Friedman, 2009[60]; Makles, 2012[61]) is used to identify consistent sets of firms. The description of the results below is based on 6 clusters. The number of clusters has been chosen as a compromise between the share of variance explained by the clustering (60% of the variance in the sample with 6 clusters) and the interpretability of the clusters. Similar results are obtained with a k-medians algorithm.

#### Results

The results display 3 clusters of patenting firms and 3 clusters of non-patenting firms (Table 3).

The first cluster consists of old and very large firms (median employment above 12k employees), with a broad patent portfolio, including on emerging technologies. These firms are rarely foreign-owned and only half of them is in the automotive sector.

The second cluster is also made of old and rather large firms, although it also includes smaller firms. They display a smaller patent portfolio, with few patents in emerging technologies. Only one fourth of these firms are in the automotive sector.

Firms in the third cluster have characteristics similar to the firms in the second cluster, except that their patent portfolio is smaller and more concentrated on emerging technologies, in particular hydrogen. The vast majority of these firms are not in the automotive sector.

Clusters 4 to 6 include firms with a very low number of patents, with a vast majority of firms being in the automotive sector. Cluster 4 contains medium-sized (median employment above 100 employees) and old firms, cluster 5 small and old firms and cluster 6 small and young firms.

## Table 3. Characteristics of firms by cluster

| Class | # of firms | Median age | Share of foreign firms | Median employment | Median number of patents | | | | | Share of firms in the automotive sector |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Autonomous | Combustion | Electric | Hydrogen | Total automotive | |
| 1 - Very large firms | 56 | 73 [23-115] | 4% | 12 027 [247-66 583] | 23 [2-222] | 54 [3-305] | 64 [19-312] | 7 [0-120] | 263 [15-1 165] | 41% |
| 2 - Non automotive - Patents in traditional technologies | 465 | 48 [14-91] | 24% | 1 049 [44-7 916] | 0 [0-8] | 1 [0-8] | 1 [0-6] | 0 [0-1] | 14 [0-111] | 25% |
| 3 - Non automotive - Patents in emerging technologies | 162 | 69 [14-101] | 7% | 1 158 [14-11 401] | 0 [0-2] | 0 [0-2] | 0 [0-6] | 4 [2-18] | 2 [0-56] | 4% |
| 4 – Medium-sized non-patenters | 10 937 | 26 [9-67] | 20% | 109 [36-785] | 0 [0-0] | 0 [0-0] | 0 [0-0] | 0 [0-0] | 0 [0-3] | 64% |
| 5 - Non-patenters - Old and small | 23 169 | 17 [9-38] | 1% | 4 [1-18] | 0 [0-0] | 0 [0-0] | 0 [0-0] | 0 [0-0] | 0 [0-0] | 90% |
| 6 - Non-patenters - Young and small | 22 451 | 4 [1-7] | 1% | 5 [1-31] | 0 [0-0] | 0 [0-0] | 0 [0-0] | 0 [0-0] | 0 [0-0] | 98% |

Note: See methodology section above. Patents in one of the four technologies (combustion, electric, hydrogen and autonomous) are not necessarily included in the 'total automotive' category due to different selection criteria, and vice versa. The numbers in brackets correspond to the 10th and 90th percentile.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2022; Orbis; OECD calculations.

# 5 Mergers and Acquisitions are also reflecting the growing importance of the twin transitions

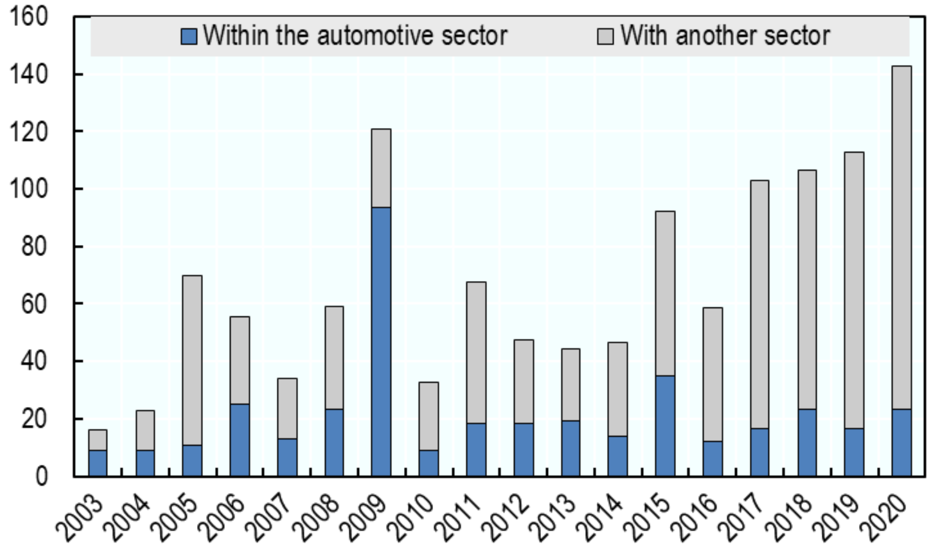
This section describes mergers and acquisitions (M&As) involving at least one firm in the automotive sector, either as an acquirer or as a target of the transaction.

It shows that the M&A activity in the automotive ecosystem has grown significantly over the last decade. This growth partly reflects the increasing role of emerging technologies and M&As as a way to acquire external knowledge, know-how and talents. ICT firms become an important target of automotive acquirers and the patent portfolio of target firms is more oriented towards autonomous and electric vehicles technologies. Cross-border and cross-industry M&A activity is driven by Chinese, Japanese, US and British acquirers, whereas European firms are a prime target of cross-border M&As.

## M&A activity is increasingly cross-sectoral and illustrates the growing importance of the ICT sector in the automotive ecosystem

The value of M&A, minority stake and joint venture deals between the automotive industry and other industries has increased steadily between 2003 and 2020 (Figure 28). Deals with non-financial firms outside the automotive industry, in particular from the service sectors, significantly contributed to this growth.

## Figure 28. Real value of deals involving at least one firm from the automotive sector, by year and by deal partner, in billion constant 2005 USD



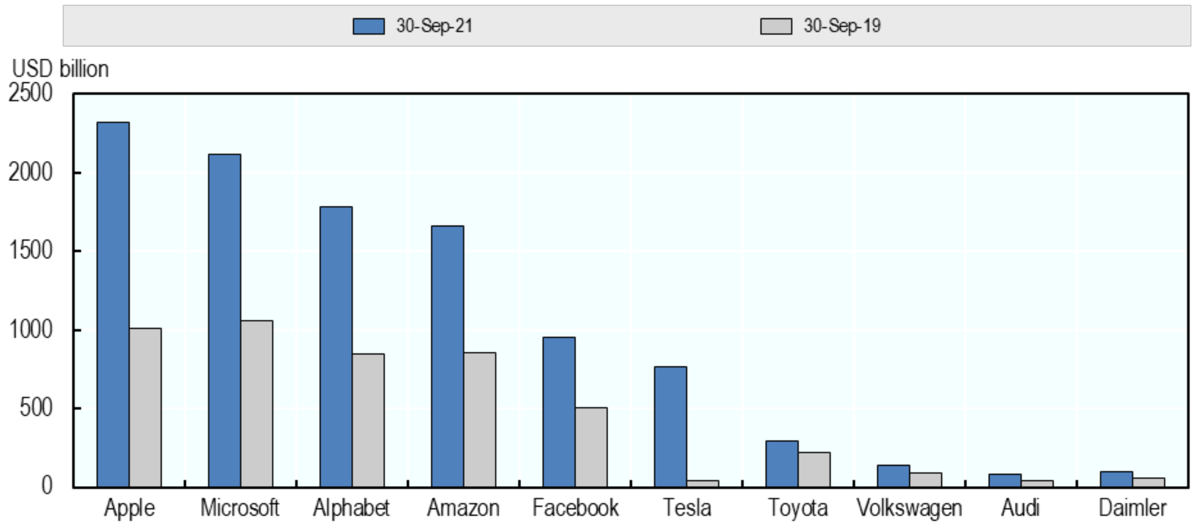

Note: "Within the automotive sector" refers to deals with firms belonging to ISIC Rev.4 Division 29 on both sides. "With another sector" refers to deals with a firm belonging to ISIC Rev.4 Division 29 on one side only. This figure covers the value of deals in the following categories: "genuine acquisition", "further acquisition", "minority stakes" and "joint venture". Data for 2020 are preliminary, subject to revision, and should be interpreted with caution.
Source: Zephyr data; OECD calculations.

Automotive firms do not necessarily have the relevant skills, know-how or critical mass to develop the new software-driven innovation. To address this, several car producers have formed multiple alliances across industries, including with ICT giants (e.g. Toyota[21] and Alphabet[22]), in order to mutualise investments. Up until now, this strategy seems to have helped them keep up with their competitors from other sectors (Figure 24).

Going forward, the investment capacity of car producers may come short of that of ICT giants, which are much larger as proxied by market capitalisation (Figure 29). The COVID-19 crisis, which has affected the automotive sector more severely than the ICT sector, has further widened this size gap. In addition, the latest OECD Main Science and Technology Indicators show a sharp drop in 2020 in R&D expenses of selected top R&D companies in the automotive sector, as opposed to stable growth in R&D expenses of the ICT firms (Figure 30). The crisis may therefore have a long-lasting effect on the automotive sector's relative capacity to invest in the development of new technologies.

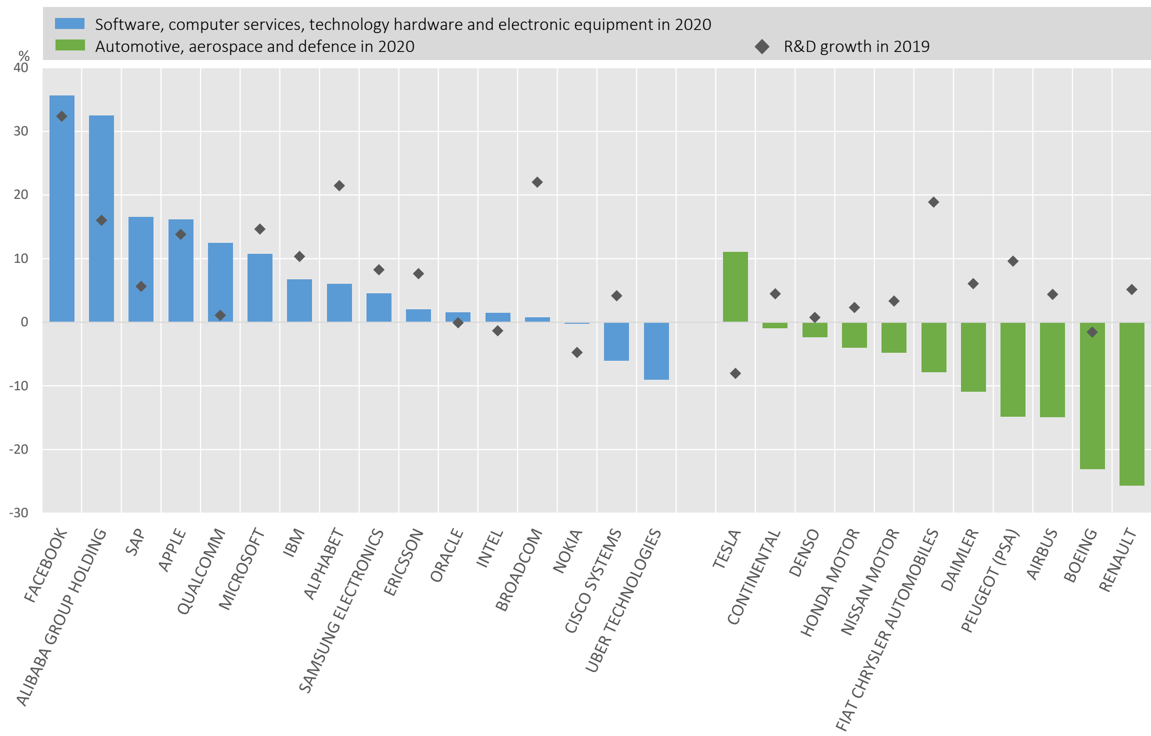
## Figure 29. Automotive sector firms are competing with the top ICT firms

Market capitalisation of the top 5 automotive firms and the top 5 ICT firms involved in the autonomous vehicle development across OECD countries as of 30 September 2019 and 30 September 2021, in billion USD




Source: Eikon; OECD calculation.

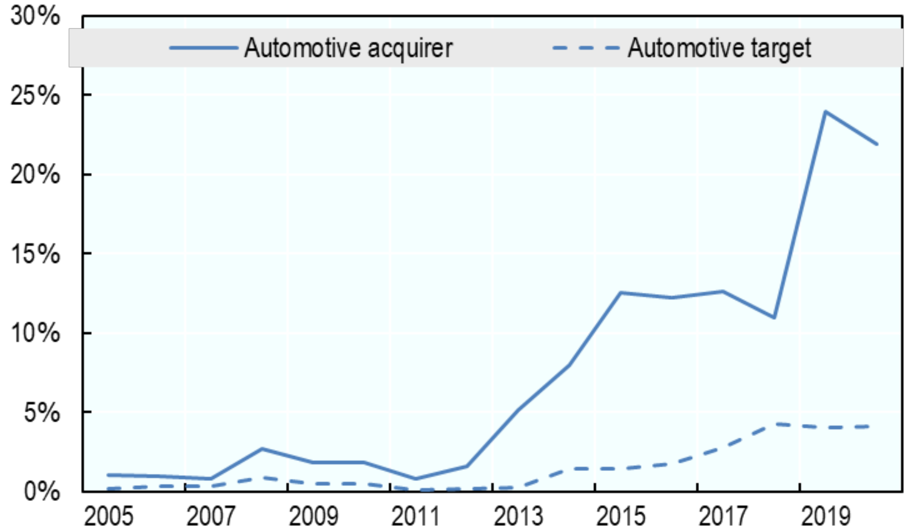
## Figure 30. Reported nominal R&D expense growth in selected top R&D companies, 2020




Source: OECD calculations based on published annual and interim business financial reports, OECD Main Science and Technology Indicators Highlights on R&D expenditure, www.oecd.org/sti/msti-highlights-march-2021.pdf, March 2021.

For the time being, however, M&As data reveal that automotive firms are more and more targeting their acquisitions toward ICT firms (Figure 31), whereas acquisitions of automotive firms rarely involve ICT firms. This further highlights the increasing synergies between the automotive sector and markets and technologies from other industries through the M&A channel.

### Figure 31. Share of ICT firms in acquisitions by automotive firms and in acquirers of automotive firms

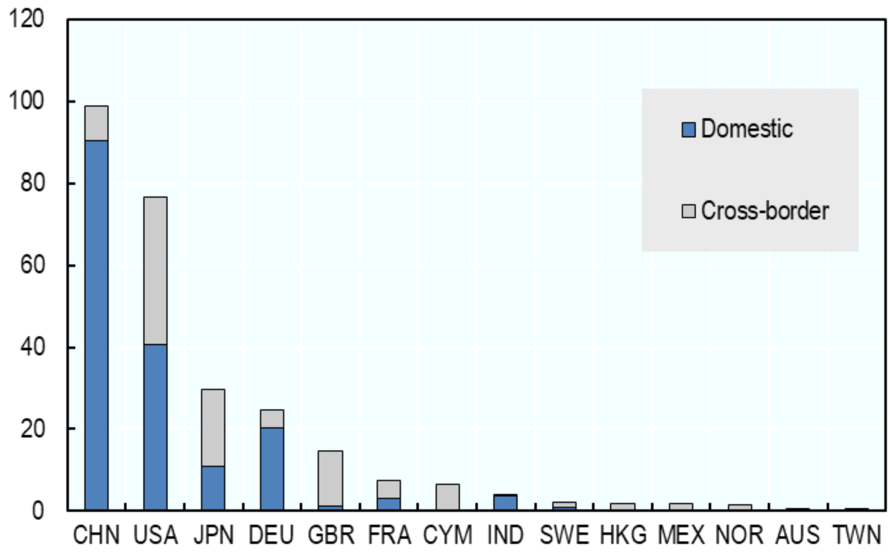



Note: 3-year rolling averages. In 2020, more than 20% of acquisitions by an automotive firm target ICT firms. Conversely, less than 5% of acquisitions of automotive firms are initiated by ICT firms. This figure covers the value of deals in the following categories: “genuine acquisition”, “further acquisition”, “minority stakes” and “joint venture”. Data for 2020 are preliminary, subject to revision, and should be interpreted with caution. ICT sectors include ISIC Rev.4 Divisions 26, 58, 62 and 63.
Source: Zephyr data; OECD calculation.

## US, UK and Japan are the most active on cross-border M&As; China, the US and Japan on cross-industry M&As

China is the most important acquirer, but the United States, Japan and the United Kingdom are the most active on international transactions (Figure 32).

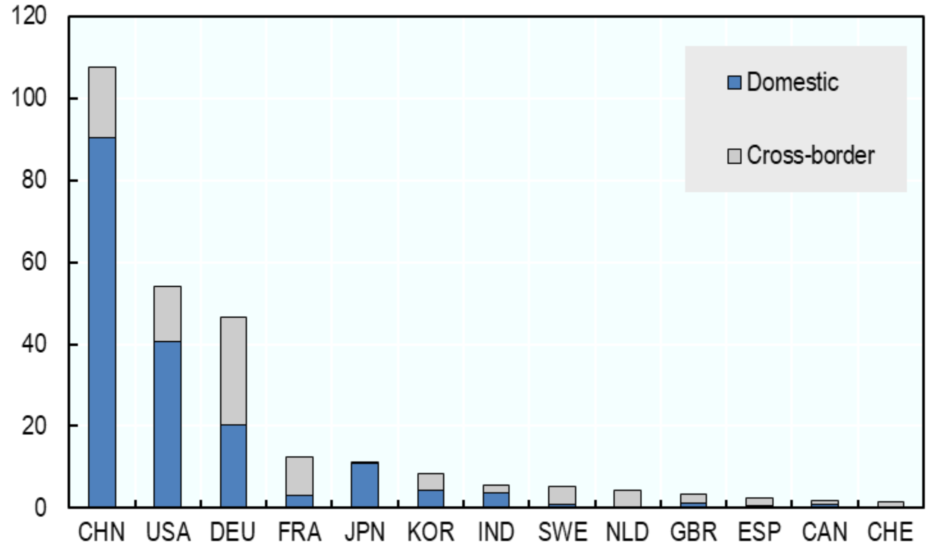
### Figure 32. Value of transactions by economy of acquiring firm, 2016-2019, in billion constant 2005 USD




Note: This figure covers the value of deals involving at least one firm in the automotive sector, either as an acquirer or as a target of the transaction, and in the following categories: “genuine acquisition”, “further acquisition”, “minority stakes” and “joint venture”. Transactions with missing economy for the acquirer or the target are not considered.
Source: Zephyr data; OECD calculation.

Targets of cross-border transactions are located in Germany, China, the United States and several other European countries (e.g. France, Sweden, the Netherlands, see Figure 33). China and the United States record the largest value of acquisitions, but these are to a large extent driven by domestic transactions. On the contrary, for Germany and several other European countries, transactions mainly consist in cross-border M&As. Interestingly, whereas Japanese companies are very active to acquire foreign firms, the acquisition of Japanese firms is almost exclusively initiated by domestic firms.

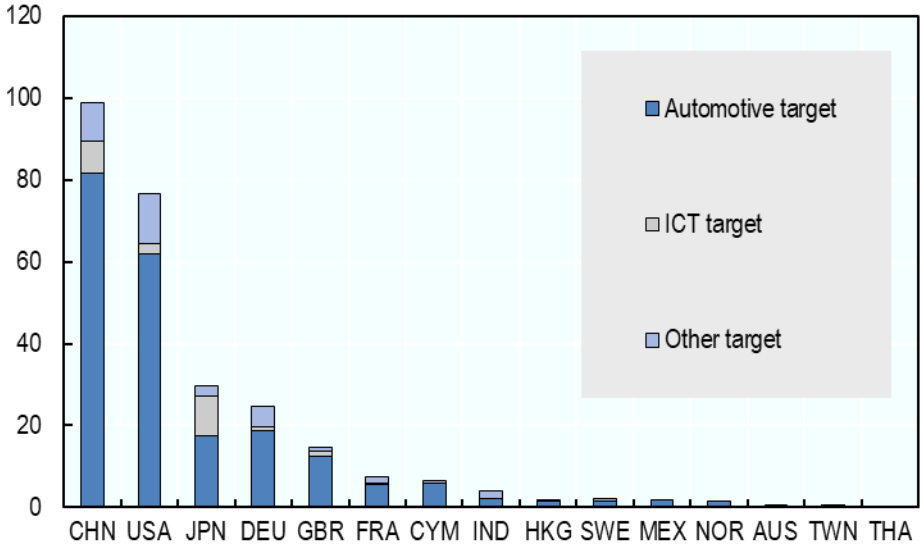
## Figure 33. Value of transactions by economy of target firm, 2016-2019, in billion constant 2005 USD




Note: This figure covers the value of deals involving at least one firm in the automotive sector, either as an acquirer or as a target of the transaction, and in the following categories: "genuine acquisition", "further acquisition", "minority stakes" and "joint venture". Transactions with missing economy for the acquirer or the target are not considered.
Source: Zephyr data; OECD calculation.

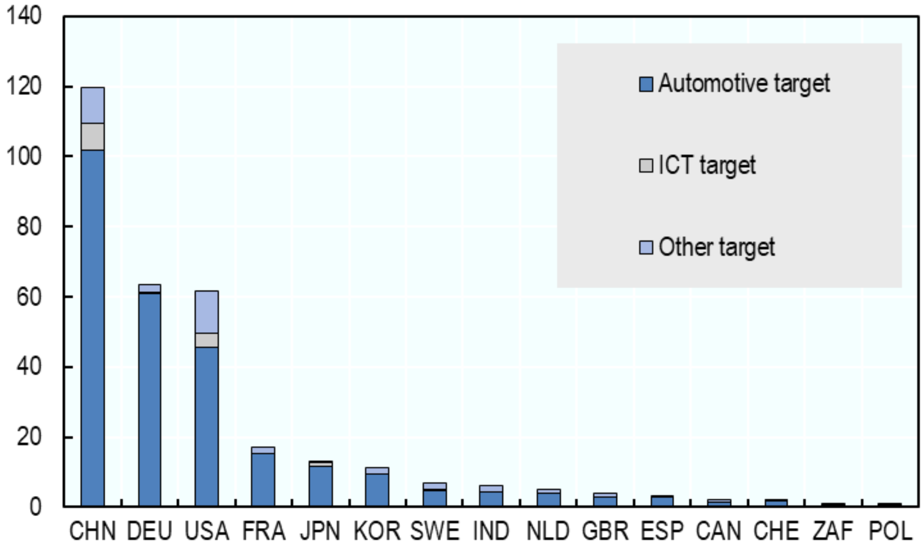
China, the United States and Japan are the most active acquirers in cross-industry transactions (Figure 34). China and Japan are the most important acquirers of ICT firms by automotive firms. Non-automotive targets are mainly located in China and the United States (Figure 35).

## Figure 34. Value of transactions by economy of acquiring firm and by sector of the target, 2016-2019, in billion constant 2005 USD




Note: This figure covers the value of deals involving at least one firm in the automotive sector, either as an acquirer or as a target of the transaction, and in the following categories: "genuine acquisition", "further acquisition", "minority stakes" and "joint venture". Transactions with missing economy for the acquirer or the target are not considered. Transactions with missing sector for the the target are not considered.
Source: Zephyr data; OECD calculation.

## Figure 35. Value of transactions by economy and sector of the target, 2016-2019, in billion constant 2005 USD



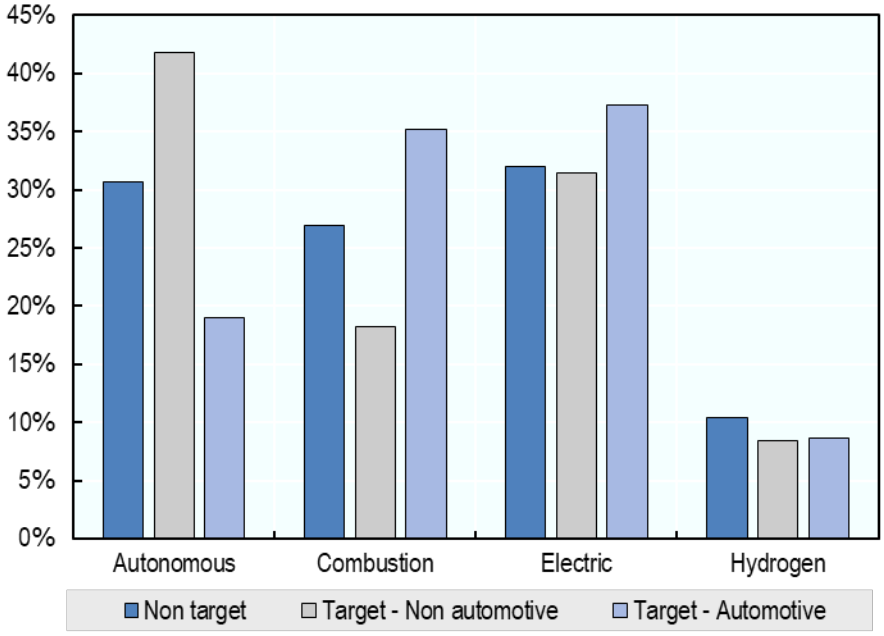

Note: This figure covers the value of deals involving at least one firm in the automotive sector, either as an acquirer or as a target of the transaction, and in the following categories: "genuine acquisition", "further acquisition", "minority stakes" and "joint venture". Transactions with missing sector for the the target are not considered.
Source: Zephyr data; OECD calculation.

## M&A is a strategy to acquire external knowledge and experience, in particular on autonomous and electric vehicle technologies

M&A is often cited as a strategy to acquire external knowledge (Cassiman et al., 2005[62]; Phillips and Zhdanov, 2012[63]). If this is indeed the case, the patent portfolio of target firms should reflect the technologies of interest for acquiring firms. As transactions within the automotive sector can be driven by other motives, such as industrial synergies or entry in a new market, target firms outside the automotive sector are more likely to be bought for their technologies.

Compared to firms that are not the target of an M&A, target firms outside the automotive sector have a much higher proportion of patents in autonomous vehicle technologies (Figure 36). On the contrary, they have a significantly lower share of patents related to combustion engines. Targets firms in the automotive sector tend to have a higher share of patents in combustion and electric engine technologies.

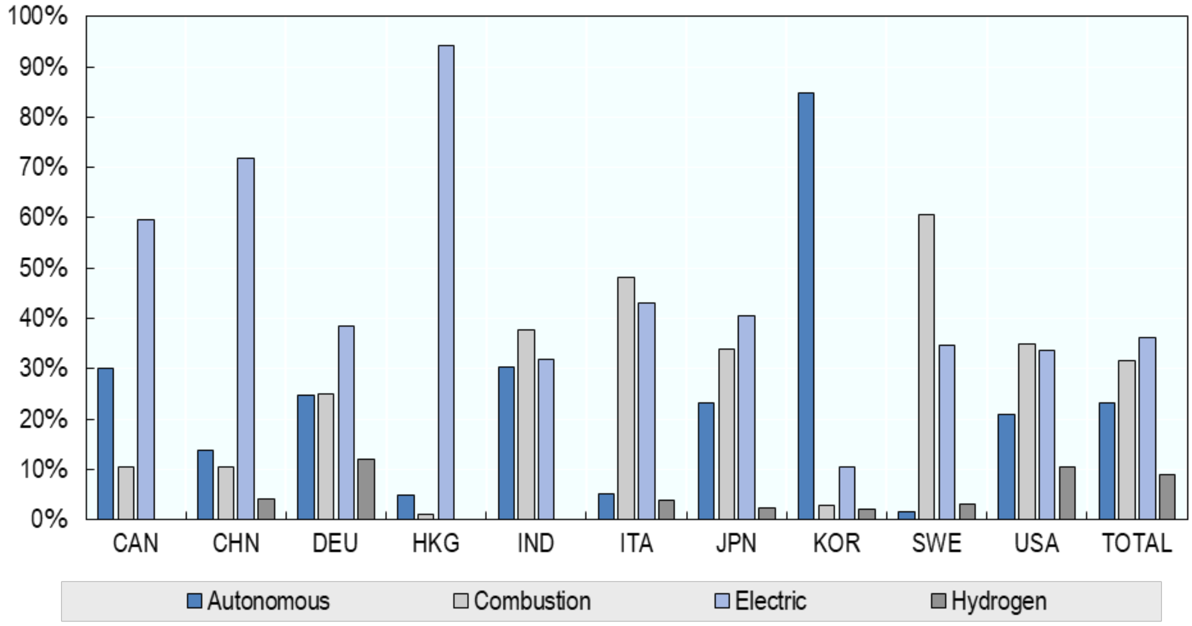
### Figure 36. Patent portfolio of selected firms, by technology, 2016-2019




Note: This figure covers the deals in the following categories: “genuine acquisition”, “further acquisition”, “minority stakes” and “joint venture”. See Figure 12 for the definition of patent families. The methodology is described in detail in Annex A. Non target firms correspond to firms having filed patents in at least one of the 4 selected technologies.
Source: Zephyr data; OECD calculation.

The patent portfolios of acquired firms vary significantly across acquiring economy (Figure 37). Firms from Canada, China and Hong-Kong (China) disproportionately target firms with electric engine patents, whereas Korean firms mostly acquire firms specialised in autonomous vehicles.

**Figure 37. Patent portfolio of target firms, by technology and by acquiring economy, 2016-2019**




Note: This figure covers the deals in the following categories: “genuine acquisition”, “further acquisition”, “minority stakes” and “joint venture”. It is restricted to economies whose firms have acquired targets with at least 30 patents over the period and for which the three most important transactions represent less than 60% of the patent portfolio of the targets. See Figure 12 for the definition of patent families. The methodology is described in detail in Annex A.
Source: Zephyr data; OECD calculation.

# 6 Defining the automotive ecosystem

Input-output linkages are a major component in the makeup of industrial ecosystems, but fall short of accounting for other relevant linkages (Box 1). In particular they do not take into account:

- Technological similarities and emerging trends. Even if sectors are not part of the same value chain, they may share important technologies or face the same technological challenges. This can be observed from their investments in knowledge and skills, which can be proxied by patents or M&A activities. These linkages may become apparent before actual input-output flows occur between sectors.
- The contribution of downstream and upstream sectors through capital goods. Input-output flows account for intermediate consumption, but do not allow identifying linkages channelling through gross fixed capital formation in goods or services produced by another industry.

There is no agreed operational definition of industrial ecosystems and their demarcation necessarily relies on arbitrary choices regarding weights attributed to different layers (e.g. input-output linkages vs technological linkages vs financial linkages) and thresholds to determine sectors inside and outside the ecosystem. More fundamentally, a conceptual framework to identify the relevant layers and inform the above-mentioned arbitrary choices is lacking.

In the same vein, additional insights could be obtained by analysing linkages at the microeconomic level (e.g. through firm-level transaction data), rather than at the sectoral level, in order to account for the important within sector heterogeneity. This would allow for instance identifying the firms in the 'basic metals' sector which contribute to the automotive ecosystem.

The remainder of this section proposes a list of sectors that could be considered as part of the automotive ecosystem. Box 4 describes the 'mobility-transport-automotive' ecosystem defined by the European Commission and explains the main differences with the ecosystem defined in this paper.

This paper identifies 14 sectors that constitute the automotive ecosystem.

- First, the automotive ecosystem contains the 'Manufacture of motor vehicles, trailers and semi-trailers' and the 4 other sectors identified in the analysis of input-output linkages (see section 2, 'Wholesale and retail trade and repair of motor vehicles and motorcycles' – ISIC Rev.4 Division 45, 'Manufacture of rubber and plastics products' – ISIC Rev.4 Division 22, 'Manufacture of basic metals' – ISIC Rev.4 Division 24 and 'Manufacture of fabricated metal products, except machinery and equipment' – ISIC Rev.4 Division 25).
- Second, technological similarities are likely to arise with the 'Manufacture of other transport equipment' (ISIC Rev.4 Division 30). The latter, which includes shipbuilding, manufacture of railway rolling stock and aerospace and military vehicles, also faces challenges related to autonomous driving and the transition towards carbon neutrality (Jha, 2016[64]; Montero, Finger and Serafimova, 2021[65]; OECD, 2020[53]).
- Third, Section 4 shows that other sectors, such as 'Machinery and equipment' (ISIC Rev.4 Division 28), 'Manufacture of electrical equipment' (ISIC Rev.4 Division 27) and ICT sectors ('Computer, electronic and optical equipment' ISIC Rev.4 Division 26, 'Publishing activities' including publishing

of software, ISIC Rev.4 Division 58 and 'IT and other information services' ISIC Rev.4 Divisions 62 and 63) are also active in developing and supplying technologies for the automotive sector.

- Fourth, motor vehicles represent a significant part of investment in other sectors. Although there are no cross-country harmonised sectoral data on gross fixed capital formation (GFCF) by asset, transport equipment consistently represents a high share of GFCF in the 'Land transport and transport via pipelines' sector (ISIC Rev.4 Division 49) (e.g. 45 % in the United Kingdom, 43 % in the United States[23]), which use automotive goods as capital in the provision of services such as transport of passengers and freight transport, and 'Rental and Leasing activities' (ISIC Rev.4 Division 77) (e.g. 80 % in the United Kingdom, 66 % in the United States). Conversely, the automotive sector relies on investment in machines (e.g. 30 % of the sectoral GFCF in the United Kingdom, 39 % in the United States), produced in the 'Machinery and equipment' sector (ISIC Rev.4 Division 28).

Figure 38 shows, for the European Union, the input-output linkages of this ecosystem in 2018. These ecosystem sectors correspond to the automotive value chain extended with sectors with potential linkages through capital goods, sharing important technologies and facing the same technological challenges[24].

## Figure 38. Input-output linkages in the automotive ecosystem in the European Union

Flows representing more than USD 5.8 billion at current prices, 2018


Note: Nodes are weighted by value added. Final demand nodes are not weighted. Edges are weighted by the magnitude of the flows. Final demand towards EU27 and non-EU27 countries are placed at the bottom of the diagram.
Source: OECD, Inter-Country Input-Output (ICIO) Database, http://oe.cd/icio,February 2022.

### Box 4. The European Commission's industrial ecosystems - Mobility-Transport-Automotive

Following a different approach to identify industrial ecosystems (see below), the European Commission partitioned the EU-27 economy into 14 industrial ecosystems, where sectors can be attributed to one ecosystem, split between a few ecosystems, or considered as horizontal, i.e. serving multiple ecosystems. The main criteria used to assign sectors into ecosystems are, first, similarity between economic activities, and second, input-output linkages.

The automotive sector is included in the 'Mobility-Transport-Automotive' ecosystem (European Commission, 2021[66]). This ecosystem also includes 'Wholesale and retail trade and repair of motor vehicles and motorcycles' and parts of other sectors (Table 4). For instance, 32 % of the 'Manufacture of other transport equipment' sector is considered part of this ecosystem, the rest being allocated to the 'Aerospace and Defence' ecosystem; and 52% of the 'Land transport and transport via pipelines' sector is associated to the ecosystem, the rest being allocated to the 'Tourism' ecosystem. Finally, 'Manufacture of fabricated metal products' and 'Manufacture of machinery and equipment' are the most important horizontal sectors contributing to this ecosystem.

#### Table 4. Main sectors of the Mobility-Transport-Automotive ecosystem

| Sector | ISIC Rev 4. | Share of value added attributed to the ecosystem |
|---|---|---|
| Manufacture of motor vehicles, trailers and semi-trailers | 29 | 100% |
| Wholesale and retail trade and repair of motor vehicles and motorcycles | 45 | 100% |
| Land transport and transport via pipelines | 49 | 52% |
| Manufacture of fabricated metal products, except machinery and equipment | 25 | 24% |
| Manufacture of machinery and equipment n.e.c | 28 | 28% |
| Warehousing and support activites for transportation | 52 | 39% |
| Manufacture of other transport equipment | 30 | 32% |
| Water transport | 50 | 78% |

Note: For the sake of simplicity, this table only includes sectors with more than 3% of their value added linked to the 'Mobility-Transport-Automotive' ecosystem.
Source: European Commission (2021[66]).

There are several noticeable differences between the approach followed by the European Commission and the one used in this paper. Whereas this paper aims at identifying the ecosystem centred around the automotive sector by considering input-output, capital, technological and financial linkages, the European Commission's objective is to partition the business sector into ecosystems according to the similarity of economic activities, common challenges linked to innovation and the twin transitions, and input-output linkages, with some sectors split between several ecosystems.

- For this reason, the European Commission considers that 'Water transport' (ISIC Rev.4 Division 50) and 'Warehousing and support activities for transportation' (ISIC Rev.4 Division

52) are included in the Mobility-Transport-Automotive ecosystem. These sectors have strong links with 'Manufacture of other transport equipment' (ISIC Rev.4 Division 30) and 'Land transport and transport via pipelines' (ISIC Rev.4 Division 49) respectively, but this paper shows that input-output linkages with the automotive sector are more tenuous.

- For sectors assigned to several ecosystems, the European Commission defines the corresponding value added weights relying 'on more granular datasets when available (e.g. defined at the 3-digit sectoral level), or based on existing studies' (European Commission, 2021, p. 208[66]), with the inclusion criterion being the similarity with the economic activity of the main sectors of the ecosystem.

# 7 Business dynamism in the automotive ecosystem

This section studies the microstructure of the automotive ecosystem, in terms of composition, productivity levels and dispersion and business dynamics, based on the Orbis database, as well as the distributed microdata projects Dynemp (OECD, 2022[67]) and Multiprod. Relying on the definition of the automotive ecosystem laid out in the previous section and in accordance with the granularity of Dynemp and Multiprod, the ecosystem is divided into several sectors: ‘transport equipment’ (ISIC Rev.4 Divisions 29 and 30), ‘input providers’ (ISIC Rev.4 Divisions 22, 24, 25 and 45) , ‘users of transport capital’ (ISIC Rev.4 Divisions 49 and 77) and ‘technology providers’ (ISIC Rev.4 Divisions 26, 27, 28, 58, 62 and 63).

It shows that the transport equipment sector is composed of larger firms and more multinational enterprises, with a relatively low level of productivity dispersion across firms. Despite this dominance of large incumbents, the transport equipment sector, but also its technology providers, experience a higher growth of employment compared to the rest of manufacturing, partly driven by the rapid growth of young firms and, for technology providers, by a higher entry rate.

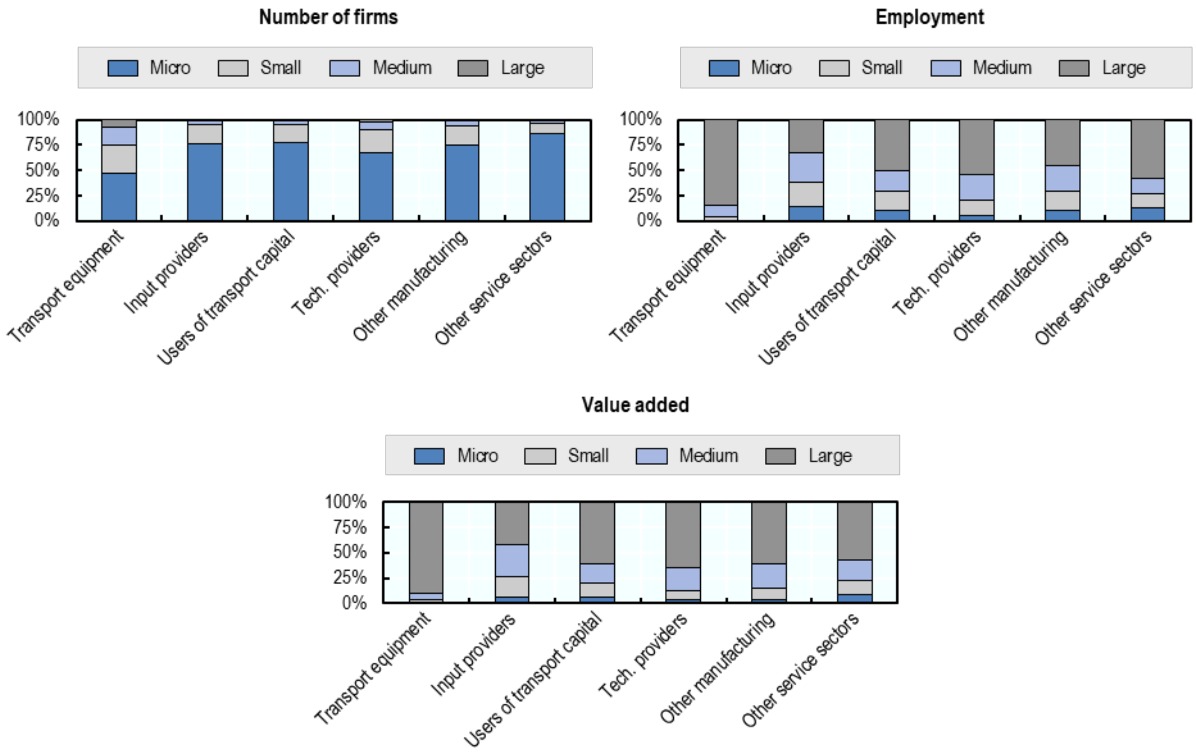
## The core of the ecosystem is dominated by large firms and MNEs

The transport equipment sector is characterised by the importance of large firms, in terms of number of firms, employment and value added, compared to other manufacturing sectors (Figure 39).

On the contrary, input provider sectors display a higher share of small and medium-sized firms in employment and value added (Figure 39). The other sectors of the automotive ecosystem are comparable to the other manufacturing and service sectors of the economy.

Although these results are obtained using a limited country sample (countries for which Orbis coverage in the automotive ecosystem is sufficient), they are confirmed on different country samples using Dynemp (for the number of firms by size category or the distribution of employment) or Multiprod (for the distribution of value added)

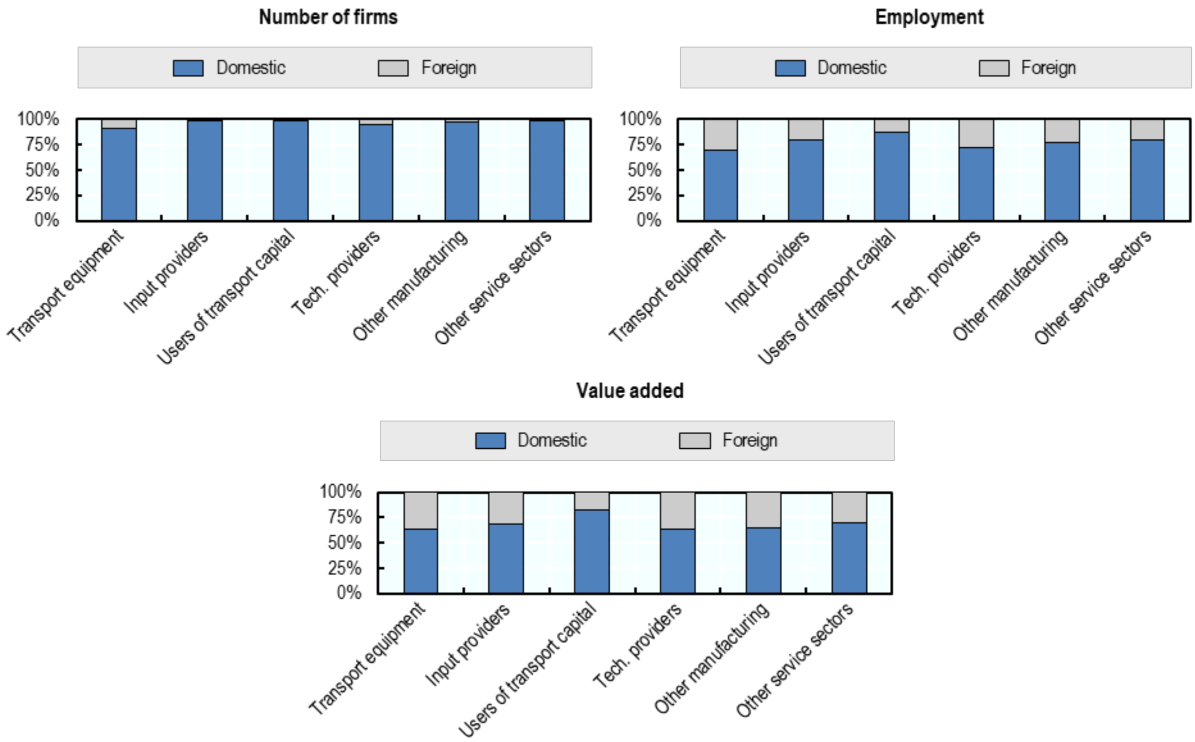
### Figure 39. Distribution of firms, employment and value added by firm size across the ecosystem, 2016-2018




Note: Country sample = France, Germany, Italy, Korea, Spain, Sweden, the United Kingdom. Size groups are based on the number of employees: Micro (1-9), Small (10-49), Medium (50-249), Large (250+).
Source: Orbis, OECD calculations.

Despite a larger share of foreign firms in the transport equipment sector, their share in labour and employment is similar to that in other manufacturing sectors (Figure 40). This is due to the larger size of domestic firms in the transport equipment sector. For the rest of the ecosystem, the importance of foreign firms is comparable to that in the other manufacturing or services sectors.

## Figure 40. Distribution of firms, employment and value added by firm ownership across the ecosystem, 2016-2018

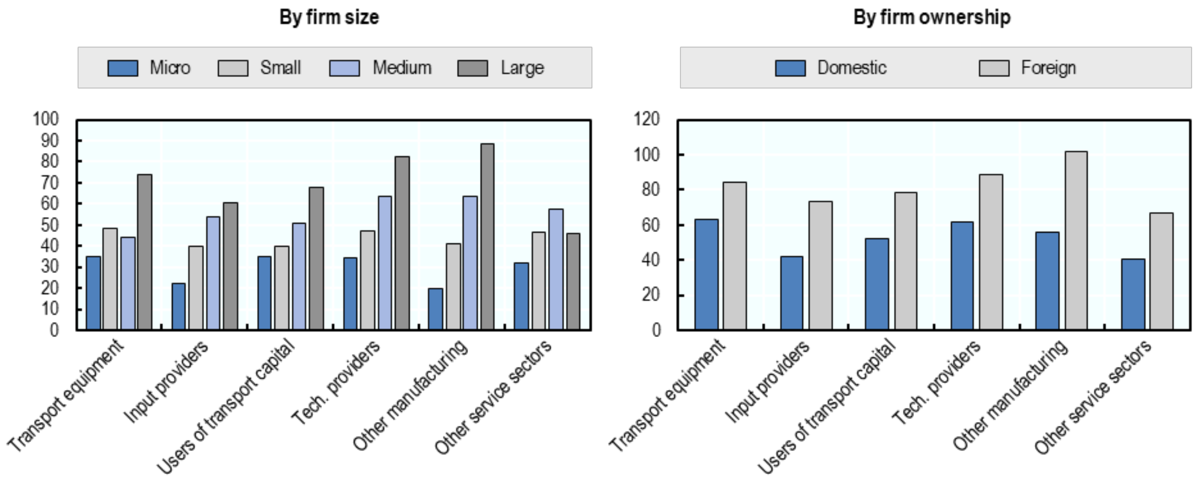



Note: Country sample = France, Germany, Italy, Korea, Spain, Sweden, the United Kingdom.
Source: Orbis, OECD calculations.

## Productivity tends to be less dispersed than in other manufacturing ecosystems

Labour productivity size premium in the automotive ecosystem is lower than in the rest of manufacturing (Figure 41). The smaller productivity size premium is confirmed using Multiprod on a different set of countries, both for labour productivity and multifactor productivity. Figure 41 also shows that the productivity premium of foreign-owned firms is lower in the automotive ecosystem compared to rest of manufacturing.

## Figure 41. Labour productivity by firm size and ownership, 2016-2019 (in thousand USD PPP per worker)

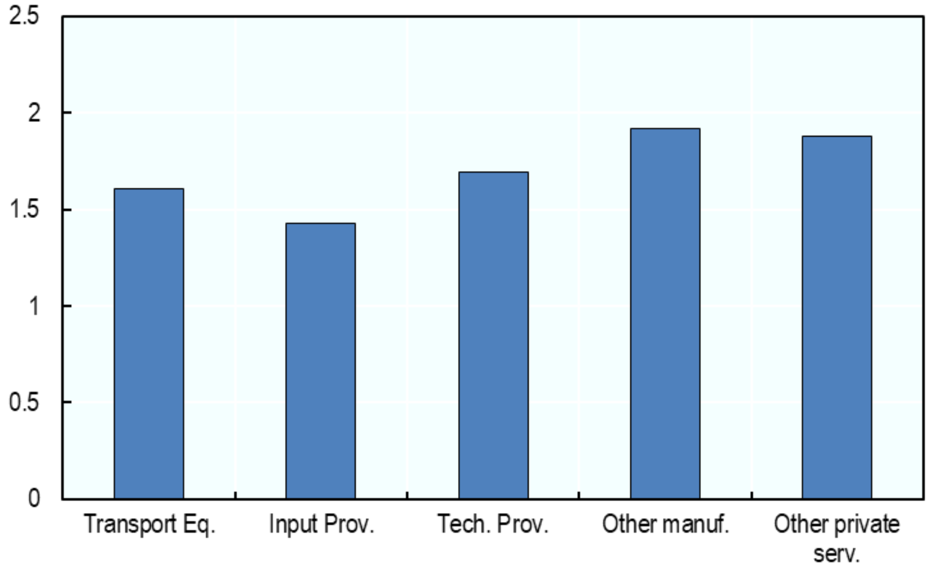



Note: Country sample = France, Germany, Italy, Korea, Spain, Sweden, the United Kingdom. Size groups are based on the number of employees: Micro (1-9), Small (10-49), Medium (50-249), Large (250+).
Source: Orbis, OECD calculations.

More generally, productivity is less dispersed in the transport equipment sector than in the rest of manufacturing (Figure 42). This also holds for the rest of the automotive ecosystem, in particular for input providers.

## Figure 42. Multifactor productivity dispersion by sector

Difference between the logarithm of multifactor productivity at the 90th and 10th percentiles of the productivity distribution, by sector

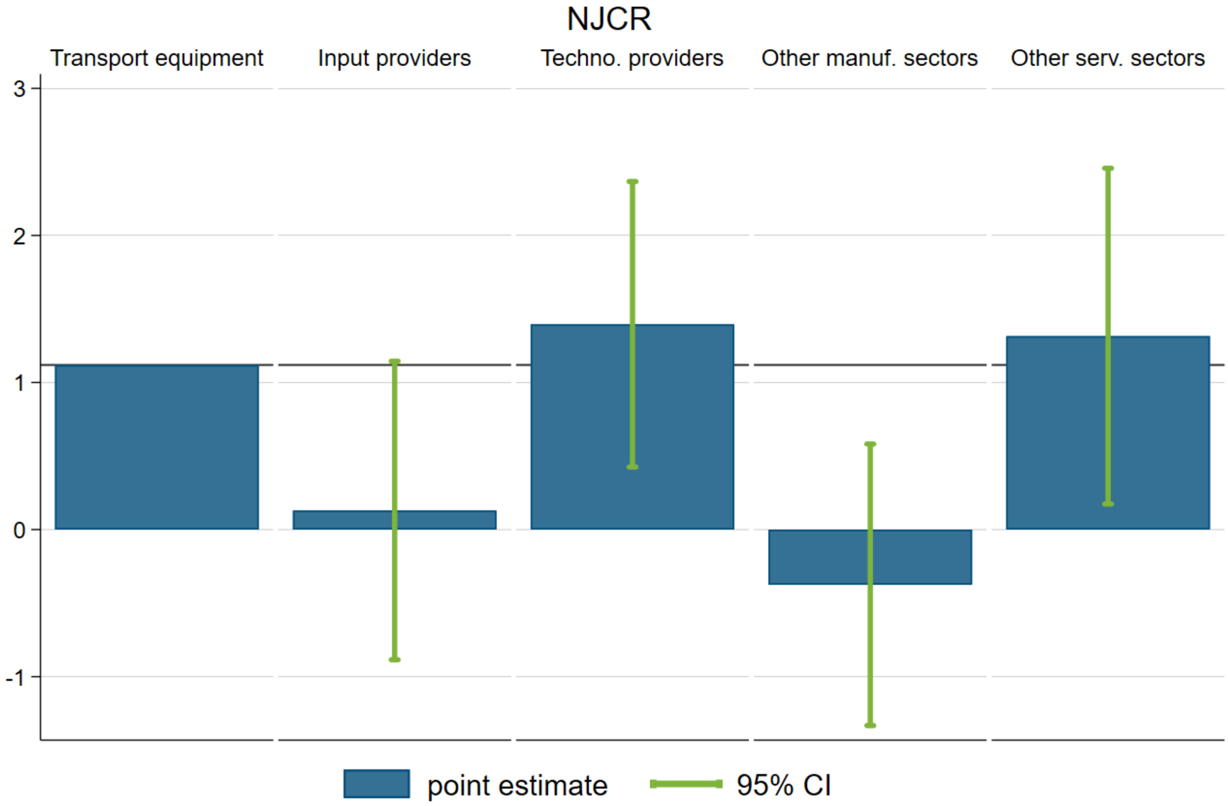



Note: Country sample: Austria, Canada, France, Hungary, Indonesia, Italy, Japan, the Netherlands, Slovenia and Sweden. Multifactor productivity is measured using the Wooldridge method. Its dispersion is measure by taking the log difference between the 90th and 10th percentiles of the productivity distribution. The 'users of transport capital' sectors cannot be identified due the level of sectoral aggregation in Multiprod.
Source: Multiprod, OECD calculations.

## And business dynamism tends to be higher in the automotive ecosystem

Employment is growing faster in the transport equipment sector and in technology providers than in the rest of manufacturing (Figure 43).

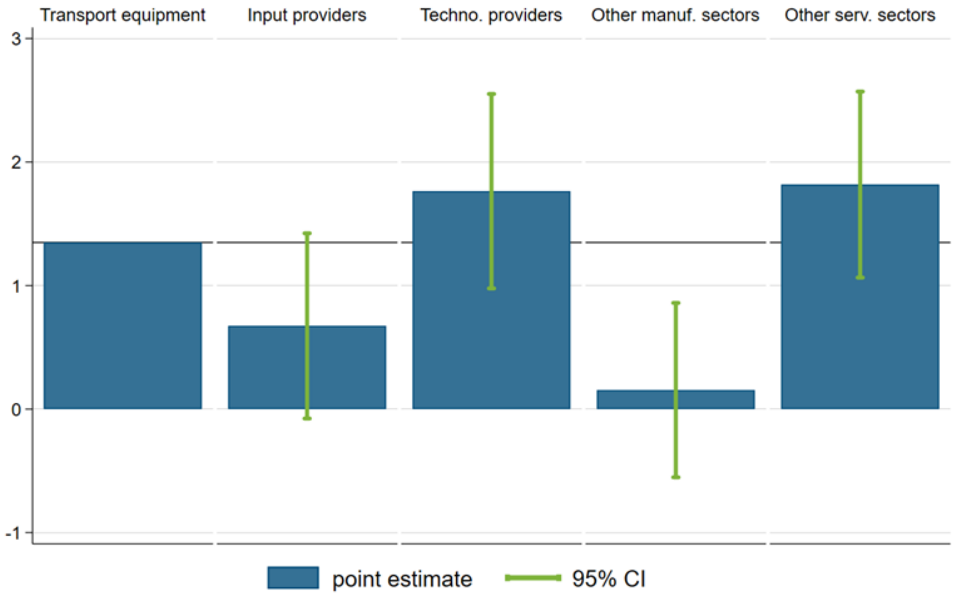
Figure 43. Net job creation rate by sector, after controlling for country-time fixed effects (in %)




Note: Country sample: Austria, Brazil, Canada, Hungary, Italy, Korea, the Netherlands, Spain, Sweden and Türkiye. This figure reports the results of a regression of net job creation rate on sector and country-time fixed effects ($Y_{c,s,t} = c + \alpha_s + \gamma_{c,t}$). The transport equipment is the baseline category, and the coefficient reported for this sector correspond to the estimated constant in the model, i.e. the average value of the indicator in the transport equipment sector ($\bar{Y}_{s=automotive}$). For other sectors, fixed effects estimates represent the difference with respect to the baseline category. For these sectors, the point estimates are rescaled by adding the constant ($c + \alpha_s$). The sample includes all available years over the period 2004-2018, but is unbalanced due to cross-country differences in terms of time coverage. The 'users of transport capital' sectors cannot be identified due the level of sectoral aggregation in Dynemp.
Source: Dynemp v3, https://oe.cd/dynemp.

This higher employment growth is driven by incumbents in both sectors, rather than by the contribution of exit or entry (Figure 44). In both sectors, this is driven by firms aged 0-2 or older than 5 years.

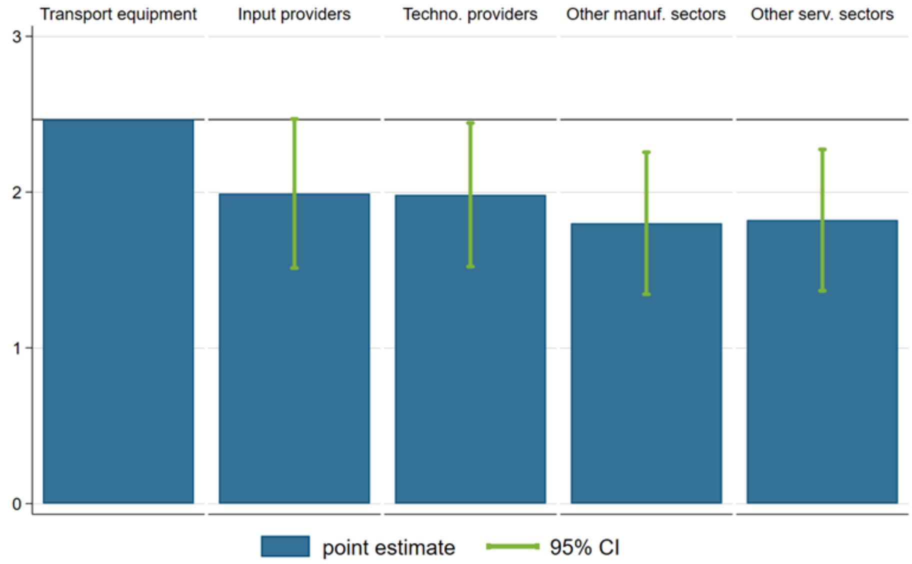
## Figure 44. Net job creation rate of incumbent firms by sector, after controlling for country-time fixed effects (in %)




Note: Country sample: Austria, Brazil, Canada, Hungary, Italy, Korea, the Netherlands, Spain, Sweden and Türkiye. This figure reports the results of a regression of net job creation rate of incumbent firms on sector and country-time fixed effects ($Y_{c,s,t} = c + \alpha_s + \gamma_{c,t}$). The transport equipment is the baseline category, and the coefficient reported for this sector correspond to the estimated constant in the model, i.e. the average value of the indicator in the transport equipment sector ($\bar{Y}_{s=automotive}$). For other sectors, fixed effects estimates represent the difference with respect to the baseline category. For these sectors, the point estimates are rescaled by adding the constant ($c + \alpha_s$). The sample includes all available years over the period 2004-2018, but is unbalanced due to cross-country differences in terms of time coverage. The 'users of transport capital' sectors cannot be identified due the level of sectoral aggregation in Dynemp.
Source: Dynemp v3, https://oe.cd/dynemp.

This contribution of young firms to employment growth is confirmed by a higher post-entry growth of new entrants in the transport equipment compared to the rest of manufacturing. Figure 45 presents the post-entry growth of young firms at the 5-year horizon, but the results remain valid at the 2- and 7-year horizon. As the entry rate is similar in this sector compared to the rest of manufacturing, this higher post-entry growth is not driven by a selection bias whereby, because of barriers to entry, only a small number of very promising firms manage to enter. This is not driven by a smaller size of firms at entry either, as firms entering into the transport equipment rather tends to be larger.

## Figure 45. Post-entry growth (5 years) by sector, after controlling for country x time fixed effects (in %)




Note: Country sample: Austria, Brazil, Canada, Hungary, Italy, Korea, the Netherlands, Spain, Sweden and Türkiye. This figure reports the results of a regression of post-entry growth on sector and country-time fixed effects ($Y_{c,s,t} = c + \alpha_s + \gamma_{c,t}$). The transport equipment is the baseline category, and the coefficient reported for this sector correspond to the estimated constant in the model, i.e. the average value of the indicator in the transport equipment sector ($\bar{Y}_{s=automotive}$). For other sectors, fixed effects estimates represent the difference with respect to the baseline category. For these sectors, the point estimates are rescaled by adding the constant ($c + \alpha_s$). The sample includes all available years over the period 2004-2018, but is unbalanced due to cross-country differences in terms of time coverage. The 'users of transport capital' sectors cannot be identified due the level of sectoral aggregation in Dynemp.
Source: Dynemp v3, https://oe.cd/dynemp.

# 8 Supporting the twin transitions in the automotive ecosystem after the COVID-19 crisis

After a brief summary of the recent automotive strategies in four countries, this section develops the main policy messages stemming from the previous sections of this paper, analysed through the lens of the OECD's conceptual framework on industrial policies (Criscuolo et al., 2022[3]).

## Governments responded swiftly to the COVID-19 crisis with specific support for the automotive ecosystem

The COVID-19 crisis has caused both supply and demand drops (OECD, 2021[68]), and created severe output losses in the automotive sector, despite massive support to demand by governments. For example, according to the OICA (*Organisation Internationale des Constructeurs Automobiles* – International Organization of Motor Vehicle Manufacturers), global production of vehicles fell by 16% in 2020, compared to 2019. Production slightly recovered in the last two quarters of 2020, but it fell again in 2021 due to the suppy-chain disruptions of key inputs such as semiconductors (Box 5).

### Box 5. Supply chain disruptions affecting the automotive ecosystem: COVID-19 crisis, semiconductor shortages and critical raw materials

The automotive industry has been particularly affected by the global shortage of semiconductors. A modern car may contain 3000 semiconductor chips, which control anything from battery management, fuel injection to infotainment systems. Guilhoto et al. (forth.[47]) show that, in most European countries and the United States, the automotive sector concentrates a large share of the impact of semiconductor shortages.

Semiconductor shortages have profoundly affected car production with significant consequences for the whole industrial ecosystem. In 2021, motor vehicle production in Europe decreased by 24% compared to the same period of 2019, while this reduction was of 16% and 19% in the United States and Japan respectively (OECD, 2021[69]). According to OECD (2021[69]), supply chain disruptions may have reduced motor vehicle production in Germany by 1.5% of GDP in the first nine months of 2021, while the impact for automotive production in Czech Republic, Japan and Mexico may have been between 0.5% and 1% of GDP. At the global level, estimates show that automotive production was 25% lower compared to a scenario without supply disruptions.

Recent semiconductor shortages reflect exceptional demand and supply shocks. Even before the COVID-19 crisis, demand for semiconductors had been exceptionally strong, partly due to stockpiling by Chinese tech players in anticipation of US export bans.[25] During the initial stages of the COVID-19 crisis, manufacturing companies in a range of industries, including motor vehicles, anticipated large drops in demand and cancelled most of their semiconductor orders. But demand for semiconductors quickly started to surge, as lockdowns and remote work triggered an increase in demand for electronic devices and motor vehicle demand recovered faster than expected when mobility restrictions were eased. Surging demand for semiconductors was accompanied by a number of exceptional supply disruptions, such as fires at Japanese production sites, droughts at US and Chinese Taipei sites and shipping delays.

The impact of these exceptional shocks has been amplified by a number of structural features of the semiconductor value chain. First, large upfront investments, long lead times and access to a highly-specialised talent pool are required to increase manufacturing capacity, implying slow adjustment of supply to surges in demand. Building a manufacturing plant for leading-edge semiconductors requires an upfront investment of 10-20 billion USD (Shih, 2021[70]). Second, demand for semiconductors is structurally increasing as a growing number of products incorporate semiconductors. Third, the semiconductor industry is concentrated in a small number of key companies and few economies, with each actor typically specialising in one specific stage of the value chain. For instance, many US semiconductor companies have adopted “fabless” business models, specialising on chip design and outsourcing manufacturing to East Asia, from where about 80% of global chip exports originate.

These vulnerabilities have given rise to a policy debate on the most appropriate ways to ensure security of semiconductor supply. Given high levels of geographical concentration, segmentation of production into multiple stages and the wide variety of differentiated products, semiconductor-users only have limited scope for diversifying their supply chains. Consequently, a number of key economies (including China, the European Union and the United States) aim to increasingly source semiconductors from close allies or reshore parts of the semiconductor value chain, with a view to achieving “strategic autonomy” (Institut Montaigne, 2022[71]).

Global semiconductors shortages are expected to decrease but could persist to some extent for several years (McKinsey, 2022[72]). Additional concerns arise from disruptions coming from the war in Ukraine, which might affect the automotive industry. Concretely, Russia is a key supplier of palladium, used in catalytic converters for cars; and nickel, used in steel production and the manufacture of batteries, both inputs used in car production. Moreover, Russia and Ukraine are sources of inert gases such as argon and neon, used in the production of semiconductors (OECD, 2022[73]).

In the longer run, the availability of some critical materials might become a binding constraint for the automotive sector, notably due to the growing demand for electric vehicles, and for batteries more generally. Critical materials used by the automotive sector include instance cobalt, lithium, graphite, niobium, silicone, titanium, phospohorus and fluorspar (European Commission, 2020[74]), or copper, neodymium or dysprosium (André and Ljunggren, 2022[75]).

Source: Based on Guilhoto et al. (forth.[47]).

The COVID-19 crisis did not only trigger temporary factory closures in many countries but, for several firms including OEMs (e.g., Nissan, Renault), it was also concomitant with permanent layoffs justified by the expected long-term transformation in the automotive ecosystem.

To weather the prolonging crisis, several governments have provided the automotive industry with financial support programmes, notably with the view to accelerate both green and technological transitions. In addition to standard justifications for industrial policy in the automotive ecosystem, governments feared that investments, in particular those required for the green transition, would slow down as a result of the COVID-19 crisis. They also wanted to secure leading technological positions for their domestic players in emerging automotive technologies (Box 6).

In the United States, the 2021 Bipartisan Infrastructure Law[26] included several demand- and supply-side measures to support the domestic development, production and deployment of electric vehicles. It provides USD 7.5 billion to develop a national charging infrastructure and USD 7 billion to accelerate innovations and facilities across the battery supply chain. In addition, the Department of Energy provides around USD 17 billion in loans to support the domestic battery supply chain.

In May 2020, France announced a sectoral support plan[27] (more than EUR 8 billion) composed of three parts: 1/ demand support through increased subsidies for the purchase of electric vehicles, an increased scrappage scheme and an acceleration of the charging infrastructure deployment, 2/ support to innovation (EUR 1.6 billion, of which EUR 700 million for battery pilot plants, EUR 600 million of equity investments, EUR 200 million for the modernisation and decarbonisation of factories and EUR 150 million for R&D and innovation) and 3/ support to struggling firms and employees (including a skill plan and support for apprenticeship). It was followed in April 2021 by an additional support plan[28]: acceleration of charging infrastructure deployment (EUR 100 million), four new campuses for automotive skills and competencies, measures to accompany the restructuring of the upstream foundry sector (through an investment fund to contribute to restructuring the sector, EUR 30 million of public support for the retraining of employees and the mobilisation of funds from the recovery plan to revitalise the most impacted areas).

In December 2020, Japan doubled the subsidy for the purchase of EVs conditional upon the use of renewable electricity[29] and has a project of grants to support domestic production of batteries.[30] The supplementary budget for fiscal year 2021 established subsidies for the purchase of electric vehicles, plug-in hybrid vehicles, and fuel cell vehicles, as well as subsidies for the development of charging and hydrogen fueling infrastructure.[31]

In June 2020,[32] Germany announced a doubling of the eco-bonus for the purchase of electric vehicles, motor vehicle tax exemptions for low-carbon cars, a replacement programme for buses and trucks to promote electric vehicles and vehicles meeting the latest emission standards and additional investment of EUR 2.5 billion for EV-related infrastructure and R&D. In addition, the federal government invested EUR 5 billion in the railway company Deutsche Bahn. Furthermore, in November 2020, Germany announced further support,[33] including a bonus programme (EUR 2 billion) for the long-term industrial transformation of the entire automotive value chain.

### Box 6. The rationale for industrial policy interventions in the automotive ecosystem

The automotive ecosystem has a long history of industrial policy interventions in OECD countries, usually focused on the automotive sector itself, with rationales that are still used nowadays. Historically, government interventions stressed:

- The economic importance of the sector and its spillovers. The automotive sector has represented a high share of total value added and employment for decades in many countries. The automotive sector is deemed as a source of "good jobs" and create positive externalities for society (better social and economic outcomes, increased cohesiveness…) (Rodrik and Sabel, 2019[1]). It also creates numerous jobs throughout its supply chain/upstream sectors, as discussed in section 2. Furthermore, at the regional level, there are some 'automotive districts', where the share of the industry in terms of VA or employment is even higher and the impact of shocks affecting the automotive sector in those regions could be catastrophic. Therefore, governments may want to smooth the impact of business cycles on workers, firms and communities.
- The high technological-level of the industry, probably leading to economies of scale and learning-by-doing. In theory, it justifies government support to help an industry climb up the learning curve.
- The negative externalities such as road safety, pollution and traffic congestion. Government mainly resorted to demand-side instruments (e.g. mandatory standards on safety and emission standards), which have significantly affected the industry.

The recent wave of support measures, and more generally of industrial strategies, acknowledges the green and digital transitions at work in the automotive ecosystem. In addition to the previous motives, governments stress:

- Coordination failures. The green and digital transformations require political leadership and industrial policies to coordinate and direct investments among firms of the automotive ecosystem.
- First-mover advantage and network effects. Those may become important features since the operation of vehicles will rely heavily on digital platforms, data and data flows. To gain this first-mover advantage, many governments support the ecosystem in several ways (e.g. regulatory sandbox for connected vehicles, AI strategies…).
- The need to maintain or accelerate the pace of the green transition. The COVID-19 crisis has accelerated some aspects of the digital transformation (e.g. telework, teleconference), but not necessarily the green transformation. This arises from two different mechanisms: i) direct effect from the pressure on firms' liquidity buffers, and ii) indirect effects, notably through the low price of oil in 2020, which might have limited the demand for EVs (OECD, 2020[76]). Therefore, some of the COVID-19 support instruments are integrated with green strategies (electric vehicles and the charging infrastructure), innovation strategies (autonomous, shared, and connected vehicles) and strategies for employment creation/preservation.

## European countries and the United States responded to rising energy prices

The increase in energy prices due to the war in Ukraine is seriously altering the European automotive ecosystem, especially the upstream energy-intensive sectors, thus affecting the input costs of car producers. Some European countries implemented support packages, which do not target the automotive ecosystem but alleviate the skyrocketing production costs in the energy-intensive industries. For instance, Germany approved a subsidy package of EUR 5 billion for energy-intensive industries in April 2022 (European Commission, 2022[77]) and Czech Republic approved a similar package of EUR 1.2[34] billion in September 2022 (Euractiv, 2022[78]). Both programs benefit important upstream sectors of the automotive ecosystem, such as 'Basic metals - ISIC Rev.4 Division 24' and 'Rubber and plastic products - ISIC Rev.4 Division 22', among others.

Supranational policies provided by the EU complements national European strategies and contribute to alleviate the energy cost burden of the automotive ecosystem. For instance, the European Commission is preparing an emergency intervention in the wholesale power market to reduce the impact of gas prices on businesses and households. This intervention would consist in a price correction mechanism that would establish, on a temporary basis, a dynamic price limit for transactions on the Title Transfer Facility (TTF)[35] gas exchange (European Commission, 2022[79]).

The United States is also affected from the effects of high energy prices, which, in combination with other factors, have significantly increased inflation (McKinsey, 2022[80]). The United States approved the new Inflation Reduction Act (IRA)[36] in August 2022. Besides fighting inflation through a significant public deficit reduction, IRA also aims to invest in domestic energy production and manufacturing – including the automotive sector, while reducing carbon emissions (Box 7).

### Box 7. The Inflation Reduction Act and its support to the greening of the automotive ecosystem

The Inflation Reduction Act (IRA) adopted in August 2022 has three objectives: i) fighting inflation through a deficit reduction; ii) investing in domestic energy production and manufacturing; and iii) reducing carbon emissions by roughly 40 percent by 2030. To limit inflation, IRA aims to achieve an historic deficit reduction of more than USD 300 billion, which would be achieved by raising USD 739 billion additional revenues, while the Act contains USD 394 billion of additional expenditures. The main environmental objective is to reach the national 2030 climate goal [37] (Jenkins et al., 2022[81]).

In terms of beneficiaries, IRA mainly targets the energy, manufacturing and automotive sectors through a variety of instruments such as subsidies, tax expenditures, loans and loan guarantees. These instruments are designed to foster domestic manufacturing capacity, increase the availability of critical inputs (both domestically and from free-trade partners) and incentivise R&D and commercialisation of innovative green technologies.

IRA notably includes tax credits linked to manufacturing production and investment, which make up to 55% of total support and strongly benefit actors of the automotive ecosystem, such as producers of EV vehicles, EV batteries, green hydrogen technologies and other types of transportation technologies. Furthermore, USD 20 billion in loans will contribute to building new domestic EV (DLA Piper, 2022[82]) plants and USD 2 billion in grants will be available for the reconditioning of existing automotive plants.

Customers will also benefit from tax credits for the purchase of used and new EVs, amounting USD 4 000 and USD 7 500 per unit respectively. To be eligible, a minimum share of the value of critical raw materials contained in the battery should be extracted, processed or recycled in North America or a country with a free trade agreement with the United States. This share will gradually increase from 40% in 2023 until 80% in 2027.

Finally, manufacturing tax credits are conditioned on certain wage and apprenticeship requirements, which are based on prevailing conditions in similar projects from the same area.

Source: Based on official law enactment of The Inflation Reduction Act: https://www.congress.gov/bill/117th-congress/house-bill/5376/text and on McKinsey (2022[83]).

## Supporting the twin transitions in the automotive ecosystem

Automotive strategies should build on existing strengths, favour the emergence of new players and ensure complementarities within the ecosystem. After the recomposition of automotive GVCs over the last decades, notably driven by an increasing demand for cars in emerging economies, a new recomposition may occur in the coming years, due to the emergence of radically new technologies that profoundly affect the ecosystem. The twin transitions bring new opportunities and markets for newcomers in the ecosystem, even if new technologies are to some extent complementary with old technologies.

### *Industrial policy should take into account the whole industrial ecosystem.*

This paper demonstrates that the automotive sector relies on a large ecosystem, composed of various sectors, firms and technologies. Disregarding these relationships and dependencies would limit the ability of industrial policy to reach its objectives.

Some of these linkages are already taken into consideration when designing automotive strategies. For instance, industrial policies whose objectives are to improve resilience or strategic autonomy in the automotive sector usually take into account upstream sectors such as production of batteries, raw materials required for these batteries or semi-conductors. As these inputs are increasingly important for the production of motor vehicles in the context of the twin transitions, building or reinforcing the resilience of the automotive sector requires securing their supply (Box 5). Recent automotive strategies include support to the battery value chain and plans to diversify the supply of raw materials. As semiconductors are a key input for a wide range of sectors, national policies to diversify their supply are usually not included in automotive strategies. Nevertheless, as a reaction to the recent global shortage, several countries are launching plans to secure their supply of semiconductors.

However, other linkages are rarely taken into account in automotive strategies.

- For instance, considering the whole ecosystem is also important to identify job reallocation and losses linked to the twin transitions. As retail trade and repair of motor vehicles are labour-intensive sectors and are likely to be deeply affected by the CASE trends, they are potentially central for job reallocation (see Annex B). Therefore, reskilling / on-the-job training policies should include these sectors. Adjustment costs linked to job reallocation can also be significant in several upstream sectors (e.g. foundries, see France above).
- In addition, looking at technologies and M&A transactions allows uncovering important linkages with the ICT sector, which are not captured through input-output relationships. Partly because they are mainly focused on green vehicles, automotive strategies seldom acknowledge the role of ICT sectors for the future of the automotive ecosystem.

This analysis also underlines the importance of considering industrial ecosystems as dynamic. For instance, linkages with ICT sectors appeared during the last decade and are growing, as a consequence of technological change. Beyond ICT sectors, the importance of the hydrogen or electricity sectors could also grow in the future.

The importance of industrial ecosystems for the formulation of industrial policy further stresses the need to develop a sound conceptual framework to identify the relevant links and define industrial ecosystems.

### *Policies should support the emergence of young firms in the automotive ecosystem*

The twin transitions lead to an increasing role for young firms in the technological landscape, in particular for autonomous vehicles- and EV-related technologies. These firms are responsible for a growing share of patents in emerging automotive technologies, tend to specialise more in core emerging technologies and rely much more than older firms on academic knowledge. Beyond knowledge creation, section 7 shows that young firms also contribute to the growth of employment in the automotive ecosystem. Moreover, they are also more affected by the challenges related to the COVID-19 crisis (OECD, 2020[84]).

Therefore, automotive strategies should systematically include instruments to support entrepreneurship and the development of young firms, which are both more vulnerable and instrumental to the automotive industrial ecosystem. Even though this paper demonstrates that OEMs and large firms still contribute very significantly to innovation in automotive technologies and that their contribution to the twin transitions is needed, governments should refrain from specifically targeting their large OEMs at the expense of new competitors. Focusing on societal challenges and emerging technologies rather than on sectoral or narrowly-defined technological criteria can avoid implicit or unintended targeting and improve the impact of automotive policies on young firms (Criscuolo et al., 2022[3]).

Policies specifically targeting young firms can also be implemented:

- As young firms face more difficulties to access finance, support should include funding mechanisms, including loans, early and late stage venture capital.

- As young automotive firms play a key role in bringing academic knowledge to the market, innovation policies for the automotive ecosystem should encourage industrial clusters where young firms and academic institutions can interact, and facilitate the development of academic spin-offs. This requires a network of cutting-edge universities and research centres to nurture the business sector. This is all the more important that academic patents in emerging technologies mostly come from the United States and Japan.

Preserving business dynamism, which is shown to be relatively sound in the automotive ecosystem, is also important. Governments need to be careful to avoid investing in the survival of non-viable firms, particularly in an environment of rapid technological change. Supporting ailing firms can have significant impacts on employment, at least in the short run, but supporting workers rather than firms could prove more efficient in the medium run (OECD, 2021[85]). In addition, Section 7 shows that young firms in the automotive ecosystem contribute more than in other sectors to employment growth, and should also therefore be considered as providing opportunities to workers, including those displaced from older automotive firms.

### *Promoting cooperation and synergies while safeguarding competition*

Given the growth in mergers and acquisitions before the COVID-19 crisis (Figure 28) and the likelihood of a new wave of mergers after the crisis, the level of competition and contestability in the ecosystem may decrease in the near future, thereby threatening innovation and the benefits for consumers. This is consistent with ongoing trends in the ecosystem that could further lower competition in the medium run, such as the large investments required for the CASE revolution, the network externalities linked to the increasing role of data or the potential increase in market segmentation (Section 3).

Nevertheless, M&As and concentration are also an effective way to acquire new knowledge, to integrate new technologies, know-how and talents in the products, and to benefit from economies of scale or scope. This is illustrated by the role of older firms as integrators of technologies (section 4) and the patent portfolio of target firms being oriented towards autonomous and electric vehicles.

In this context, it is important to find new ways to support collaboration between firms, while preserving competition and a level playing field (e.g. industrial alliances in the EU, see Box 8). This calls for:

- Ensuring that competition authorities have the adequate tools to monitor and enforce merger control. Policy analyses of competition policy in the digital sector tend to conclude in favour of a heightened control of acquisitions of start-ups by large digital platforms (Crémer, De Montjoie and Schweitzer, 2019[86]; Shapiro, 2019[87]; Furman et al., 2019[88]; Kamepalli, Rajan and Zingales, 2020[89]; Argentesi et al., 2020[90]; Motta and Peitz, 2021[91]). As acquisitions of young firms often remain below applicable thresholds, these analyses suggest to reassess them in order to review potentially problematic mergers. The conclusions of this literature may also apply to the automotive ecosystem, which is becoming more digital and prone to network effects.
- Ensuring that young and fast-growing firms can choose among several exit strategies. Being bought by a larger firm should remain a possibility, but young ventures should also be able to opt for Initial Public Offerings (IPO) or private equity funding. The development of financial markets is therefore key to allow for the growth of promising firms and to limit market concentration in the medium run. This seems to be particularly relevant for the European automotive ecosystem, which is often a target of cross-border transactions.
- Finally, competition can also be fostered by limiting market segmentation. This can notably be achieved by international cooperation on regulatory and technical standards, for instance on autonomous vehicles (e.g. homologation, see Fernandez Llorca and Gomez (2021[92])) and emissions. Technical standardisation must nevertheless balance the risk of premature standardisation vs the need to provide clarity to investors and facilitate investments (see Cammeraat, Dechezleprêtre and Lalanne (2022[30]) regarding hydrogen). In the same vein, clear

data governance rules are needed to facilitate the deployment of connected and autonomous vehicles.

### *Demand-side and other framework policies can significantly contribute to the development and the twin transitions of the automotive ecosystem*

Large investment in R&D, innovation and restructuring are required, as suggested by the slow growth of patents related to electric and hydrogen-powered vehicles (Figure 12). However, with the worsened financial capacities induced by the COVID-19 crisis, governments need to maintain public investment in innovation to support the long-term transformation of the industry.

Even if this paper does not provide direct evidence in favour of these policies, demand-side instruments are key to reach carbon neutrality and support the deployment of new technologies (Anderson et al., 2021[2]; Criscuolo et al., 2022[3]). Measures such as emission standards, subsidies to EV vehicles, penalties on high emission cars, subsidies to deployment of charging infrastructure, or regulatory standards for self-driving cars, are instrumental in creating a demand for clean and modern motor vehicles.

Beyond measures focusing on the automotive ecosystem, carbon prices and long term carbon emission targets are also necessary to set expectations and trigger investments in low carbon technologies. The availability of affordable renewable electricity is also key to ensure environmental benefits from the adoption of electric vehicles (including FCEVs).

On the contrary, although very common, scrappage schemes are shown to be of limited effectiveness. These interventions, which were intensively used after the global financial crisis, have proven to be relatively easy to implement. But their effectiveness has been questioned, in particular because they tend to shift rather than increase car demand (Hoekstra, Puller and West, 2017[93]), which may create potentially detrimental stop-and-go effects. Even ‘green’ scrappage schemes have been criticised for benefiting mainly well-off households. In turn, means-tested versions of green scrappage schemes have a hard time stimulating demand to a sufficient extent (Miller, Wilson and Wood, 2020[94]).

Similarly, even if this paper does not provide direct evidence in support of these policies, investments in infrastructure and skills are of utmost importance for the development of the automotive ecosystem. In particular:

- Investment in infrastructure is key to ensure demand for and deployment of new automotive technologies. Relevant investments include charging infrastructure (for electric and potentially hydrogen vehicles), but also 5G networks for connected and autonomous vehicles.
- To ensure that society benefits from the changing automotive industrial ecosystem in the long-term, governments should support skills upgrading, training/retraining and transition of workers towards newly emerging green and digital jobs, but also support affected areas. Support to displaced workers is often lacking or only receives a small part of the budget in the existing strategies.

## Box 8. The European Battery Alliance (EBA)

### Alliances and Important Projects of Common European Interest

Industrial alliances are a tool to facilitate stronger cooperation and joint action between all interested partners. They bring together a wide range of partners in a given industry or value chain, including public and private actors and civil society. There is no direct funding for alliances but they can benefit from the Important Projects of Common European Interest (IPCEI) framework. 6 industrial alliances already exist (European Raw Materials Alliance; European Clean Hydrogen Alliance; European Battery Alliance; Circular Plastics Alliance; European Alliance for Industrial Data, Edge and Cloud; Industrial Alliance on Processors and Semiconductor Technologies).

IPCEIs, introduced in 2014 in the context of the modernisation of state-aid rules, are a key scheme for co-ordination between EU Member States. This framework aims to encourage Member States to support projects that make a clear contribution to economic growth, jobs and the competitiveness in Europe. Within the IPCEI framework, state aid is permitted if selected projects meet the following conditions: i) contribute to strategic EU objectives; ii) involve several EU Member States; iii) involve private financing by the beneficiaries, iv) generate positive spill-over effects across the EU; and v) be highly ambitious in terms of research and innovation. Other IPCEI projects concern micro-electronics, and several others are in the pipeline (e.g. on clean hydrogen or semi-conductors).

### The European Battery Alliance

The European Battery Alliance (EBA) was launched in 2017 by the European Commission and brings together EU national authorities, regions, industry, research institutes and other stakeholders in the battery value chain. More than 440 actors joined the alliance. One of the objectives is to produce batteries for 6 million electric cars each year.

Two IPCEIs are linked to this alliance:

- In December 2019, the European Commission approved a first IPCEI on the battery value chain. Jointly notified by 7 EU Member States, it amounts to EUR 3.2 bln of public funding until 2031 and targets 17 firms. The project covers the whole lithium-ion battery value chain (raw and advanced materials; cells and modules; battery systems; repurposing, recycling and refining) and aims at improving the environmental sustainability of battery production.
- In January 2021, the European Commission approved a second IPCEI on battery innovation. Jointly notified by 12 EU Member States, it amounts to EUR 2.9 bln of public funding until 2028 and targets 42 firms.

IPCEI and Alliances come on top of horizontal support to R&D, provided at the European level through the Horizon Europe framework (formerly Horizon 2020), and support to charging infrastructure provided for instance through the Connecting Europe Facility (CEF).

Source: https://ec.europa.eu/growth/industry/strategy/industrial-alliances_fr; https://ec.europa.eu/growth/industry/strategy/industrial-alliances/european-battery-alliance_fr; https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705; https://ec.europa.eu/commission/presscorner/detail/en/IP_21_226 and https://www.ipcei-batteries.eu/.

# Endnotes

[1] This is a lower bound of the R&D contribution of the automotive sector since some automotive R&D activity could also to some extent be carried out by firms belonging to the "Scientific research and development" sector (ISIC Rev.4 Division 72).

[2] See also Guilhoto et al. (2019[101]) for previous evidence.

[3] In particular, German OEMs offshored the production of automotive components and parts to countries like Poland, Czech Republic and Slovakia. For example, some production of mechanically resistant bumpers, seat cores and diesel engines have been offshored to Poland (Knauf Industries Automotive, 2020[109]); some production of chassis parts, safety components and pressed parts have been offshored to the Czech Republic (Czech Invest, 2009[108]) and several Tier 1 producers affiliated to Volkwswagen are located in Slovakia (Globsec, 2021[110]).

[4] Pavlinek (2012[18]) shows that French automotive firms have kept a significant share of R&D activities in France but have offshored several other stages of the production process (e.g. the final assembly of the cars). Through an input-output analysis using the World Input-Output Database (WIOD) (Timmer et al., 2015[106]), Fana and Villani (2021[15]) map the outsourcing and offshoring processes in the automotive supply chain by focusing on the geographical origin of employment and value added embodied in intermediate inputs.

[5] For instance, the German automotive sector uses 27% of all industrial robots in European manufacturing (Fernández-Macías, Klenert and Antón, 2021[107]).

[6] See Deloitte (https://www2.deloitte.com/us/en/pages/manufacturing/topics/case-automotive-industry.html) or PwC (2020[35]). Sometimes the 'S' also stands for 'Smart'.

[7] According to the scale developed by the Society of Automotive Engineers (from 0: no automation to 5 : full automation), level 3 corresponds to conditional automation (e.g. traffic jam or highway chauffeurs – the automated driving system manages all aspects of the dynamic driving task in specific situations but the human driver is expected to respond to a request to intervene).

[8] Dataforce : https://www.dataforce.de/en/news/europeans-lease-and-rent-more-cars-than-ever-before/

[9] Technavio : https://www.technavio.com/report/car-leasing-market-industry-analysis

[10] According to McKinsey (2019[38]), an average high-end modern car has 100 million lines of code, 15 times more than a Boeing 787, and two times more than the large hadron collider.

[11] Chrysler (a Stellantis brand) is already selling Pacifica minivans to Alphabet's Waymo, for its fleet of driverless taxis. The minivans include Waymo's autonomous driving technology. https://www.media.stellantis.com/me-en/chrysler/press/fca-to-deliver-thousands-of-chrysler-pacifica-minivans-to-google-for-the-launch-of-its-autonomous-taxi-service-in-the-usa

[12] Regarding semiconductors, such initiatives exist in the United States (https://www.whitehouse.gov/briefing-room/statements-releases/2022/01/21/fact-sheet-biden-harris-administration-bringing-semiconductor-manufacturing-back-to-america-2/) and in the European Union (https://ec.europa.eu/commission/presscorner/detail/en/ip_22_729). Regarding batteries, the European Union launced in 2017 the European Battery Alliance (see Box 8). See also section 8 for the support to the battery value chain in the United States.

[13] See Dernis et al. (2015[95]) and Daiko et al. (2017[96]) for further discussion on the use of IP5 families.

[14] See Bajgar et al. (2020[100]) for more information on ORBIS.

[15] Patents in these four technologies (combustion, electric, hydrogen and autonomous) are not necessarily included in the 'total automotive technology patents' due to different selection criteria.

[16] Following Graham and Mowery (2003[103]), it is possible to identify "software-related" patents in this sample by using the codes G06F (Electric Digital Data Processing), G06K (Recognition of Data; Presentation of Data; Record Carriers; Handling Record Carriers) and H04L (Electric Communication Technique) from the International Patent Classification (IPC). In total, around 11.4% of autonomous vehicle patents are included in code G06G, 10% in G06K, and around 49% in H04L. Additional information on software-related patents can be found in Mann and Sager (2007[102]), Layne-Farrar (2006[104]), and Lerner and Zhu (2007[105]).

[17] See also Ma, Xu and Fan (2022[98]) for a thorough analysis of electric vehicle patents.

[18] The Katz foreign centrality is the average between the Katz forward and backward centralities (Criscuolo and Timmis, 2018[111]). It measures the influence of a node (here an economy) in a network.

[19] Across all patents filed in IP5 families in PATSTAT between 2000 and 2019, approximately 17% of patents cite patents filed by academic institutions.

[20]To assess the novelty of patent applications, inventors detail the prior knowledge that is relevant to the invention —including other patents and academic research. These references or backward citations can help determine the originality of an invention, provide a measure of the novelty of an invention and serve as an indicator of knowledge transfers in terms of citations networks (Criscuolo and Verspagen, 2008[99]).

[21] https://global.toyota/en/newsroom/corporate/31171023.html

[22] https://www.bloomberg.com/news/articles/2020-05-07/alphabet-s-dream-of-a-smart-city-in-toronto-is-over

[23] Source: National Accounts.

24 Sectors ISIC Rev.4 Division 58 (Publishing activities with software publishing among them) and ISIC Rev.4 Division 77 (Rental and leasing) are not included in the network diagram, since in the ICIO database, the former is aggregated with sectors ISIC Rev.4 Divisions 59 and 60, and the latter with sectors ISIC Rev.4 Divisions 78 and 79.

25 See The White House (2021[43]), Thorbecke (2021[112]) and Institut Montaigne (2022[71]).

26 https://www.whitehouse.gov/briefing-room/statements-releases/2021/12/13/fact-sheet-the-biden-harris-electric-vehicle-charging-action-plan/

27 https://www.economie.gouv.fr/plan-soutien-filiere-automobile# and https://www.entreprises.gouv.fr/files/files/secteurs-d-activite/industrie/automobile/dp_plan_de_soutien_a_l_automobile.pdf

28 https://www.economie.gouv.fr/plan-de-relance/nouvelles-mesures-soutien-filiere-automobile#

29 https://www.meti.go.jp/policy/mono_info_service/mono/automobile/cev/cev_hojokin.html

30 https://www.meti.go.jp/policy/mono_info_service/mono/automobile/battery/battery-grants.html

31 https://www.meti.go.jp/english/policy/external_economy/investment/pdf/0324_001f.pdf

32 https://www.bundesfinanzministerium.de/Content/EN/Standardartikel/Topics/Public-Finances/Articles/2020-06-04-fiscal-package.html

33 https://www.bundesfinanzministerium.de/Web/EN/Issues/Public-Finances/stimulus-package-for-everyone/stimulus-package-for-everyone.html

34 The scheme is provided through compensation for losses associated to high energy prices.

35 Main European gas exchange, to which many gas contracts are indexed.

36 https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/17/fact-sheet-inflation-reduction-act-advances-environmental-justice/

37 Reducing greenhouse gases emissions by 30% compared to 2005.

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# Annex A. Patent analysis – Methodology

## Overview of PATSTAT

This section provides a brief overview of the patent system and describes the key methodological steps taken to produce the figures in this paper. Patents protect intellectual property by granting its owner exclusive rights to commercialise inventions in the country of application, either directly by the inventor or through licenses to third parties. Patents applications are examined to assess their innovativeness and typically involve legal, administrative, and procedural fees. As a result, they are often used as an indicator of innovation.

The same invention can be patented in different countries—the set of patents covering the same invention across different countries is called a patent family.

The analysis presented in the main text leverages the OECD's STI MicroData Lab infrastructure. Patent data come from the Autumn 2021 version of the EPO Worldwide Patent Statistical Database (PATSTAT), covering filings of more than eighty patent offices worldwide. PATSTAT includes detailed information on patent fillings, including citations to other patents, references to the academic literature, and data on the names and residence of inventors (independent of the country in which the applications are actually filed). Squicciarini et al. (2013[50]) and Dernis and Squicciarini (2013[51]) provide additional details on the content of the Patstat database and additional indicators of patent quality, scope, reach, and impact.

An important methodological issue that arises when comparing patents across countries is the heterogeneous quality of patents. To address this issue, this analysis relies on a sample consisting in patents belonging to IP5 patent families. IP5 patent families are sets of patent applications protecting the same invention filed in at least two intellectual property (IP) offices — with at least one application filed in one of the world's top 5 patent offices (IP5). The IP5 families are: the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (CNIPA) and the United States Patent and Trademark Office (USPTO). See Dernis et al. (2015[95]) and Daiko et al. (2017[96]), for further discussion on the use of IP5 families.

In total PATSTAT includes 59.4 million patent applications corresponding to 41.1 million patent families filed between 2000 and 2019. When restricting the sample to IP5 families, there are 21.2 million patent applications corresponding to 4.7 million patent families.

## Assigning a country of origin to patent families

The following steps are used to assign a country of origin to patent families. Most of the patent applications include the country of origin of all applicants, the filing year, and the processing authority. Using this information, the country of origin is determined for each patent family using the following procedure:

- For each patent family, the earliest patent application is analysed. If all applicants in the earliest application come from the same country:
  - The patent family is assigned to that country, provided the country filed is not missing.
- If applicants come from at least two different countries

    - The patent family is assigned to the country of origin of applicants using fractional counting. The fractional counting is done based on the number of applicants (i.e if 2 applicants come from country A and 1 from country B, country A will get 2/3).
- If the earliest patent application doesn't include the address/country of the applicant
    - The patent family is assigned to the country of origin of the earliest patent applicants for which there is information about the country of origin of the applicant(s), provided there is one. The assignment is done using fractional counting.
- If there is no applicant address nor country for any applications of the patent family
    - This patent family is assigned to the country of the patent office that received the earliest patent application.

## Collaborations and citations

This section describes the methodology to identify collaborative inventions, inventions citing academic institution patents and inventions citing the non-patent literature (NPL).

A collaborative patent family is defined as a patent family where in at least one application there were at least two applicants not labelled as individuals (this includes companies, governments, hospitals, etc…). A patent family is categorised as a collaboration between a firm and an academic institution if in at least one application there were at least two applicants, one labelled as a firm and one labelled as an academic institution. A patent family is labelled as being filed by an academic institution if at least one of the patent applicants in the patent family is an academic institution. A patent family is labelled as citing an academic institution patent if at least one application in the patent family cited a patent from an academic institution. A patent family is labelled as citing the NPL if at least one patent in the patent family cites a Serial / Journal / Periodical publication, a chemical abstract, or a biological abstract. When labelling a patent family as citing the non-patent literature, the sample is restricted to those patent families that have at least one patent application at the EPO, USPTO, or the WPTO. This restriction is necessary as NPL citation table are only available for patents filed in these three offices.

## Identifying technologies deemed relevant for the automotive sector

Patents related to the automotive sector are selected among all IP5 patent families filed between 2000 and 2019. Patents in this category are identified using a concordance table between the international patent classification (by technology - IPC) and a classification of economic activity (Van Looy, Vereyen and Schmoch, 2014[52]). Table A A.1. lists the IPC codes used to select patents in this category. In total, the automotive technologies include 442 164 different patent families, accounting for 10.7% of all patents filed during the period 2000-2019.

### Table A A.1. IPC codes for automotive technologies

| Sector | IPC Code | | | | |
|---|---|---|---|---|---|
| ISIC Rev.4 Division 29 | B60B | B60D | B60G | B60H | B60J |
| | B60K | B60L | B60N | B60P | B60Q |
| | B60R | B60T | B60W | B62D | F01L |
| | F02B | F02D | F02F | F02M | F02N |
| | F02P | F16J | G01P | | |
| ISIC Rev.4 Division 30 | B60F | B60V | B61C | B61D | B61F |
| | B61G | B61H | B61J | B61K | B63B |
| | B63C | B63H | B63J | B65F 3/* | |

Note: Mapping between IPC code and industries in the automotive sector. The table was created following Van Looy, Vereyen and Schmoch (2014[52]).

## Identifying technologies on combustion and emerging technologies

The following steps are used to identify technologies related to the combustion engine and emerging technologies (hydrogen, electric, and autonomous vehicles). Patents are assigned using the following procedure:

- Internal combustion engine technologies are identified following the methodology proposed by Borgstedt, Neyer and Schewe (2017[54]). Patents in this technology are identified using IPC classes F02B, F02D, F02F, F02M, F02N and F02P. Additionally, patents in this set must include the words *vehicle*, *car*, or *automobile* in their title or abstract.
- Hydrogen patents are identified using the Corporate Patent Classification and include the application of hydrogen technology to transportation (CPC code Y02T 90/40) and fuel cells (CPC code Y02E 60/50).
- Electric engine patents are identified by adapting the methodology proposed by Borstedt et al. (2017[54]) using IPC classes Y02T10/6, Y02T10/, Y02T90/14, Y02T90/16, and Y02T90/12. Additionally, patents in this set must include the words *vehicle*, *car*, or *automobile* in their title or abstract.
- Autonomous vehicle patents are identified through a combination of IPC codes and keywords, following the method developed by Zehtabchi (2019[55]).

It is worth noting that patent families are only assigned to one single technology class. When a patent family is identified in multiple technologies, the technologies are assigned based on the following order: hydrogen, autonomous, electric, and combustion.[1] For example if a patent family can fall into the electric and combustion engines categories, it will be labelled as electric. Using this classification there are 25 978 patents related to autonomous vehicles, 22 728 to combustion engines, 27 658 to electric engines, and 8 848 to hydrogen.

## Combining patent and firm-level information

This section describes the key methodological steps taken to link patents in the automotive sector to firm-level data. Firm-level data come from Orbis, a dataset published by Bureau Van Dijk. Orbis data include information on firms, their industry of operation, date of incorporation, and ownership structure (Bajgar et al., 2020[97]).

The first step to link patent data to Orbis relies on a mapping between applicants and the Orbis unique identifier. The mapping is available through the OECD STI MicroData lab. Following this step, the patents that are not matched are analysed. Patents filed only by individuals are excluded from the analysis.

The remaining patents (unmatched and not filed by individuals) are examined by looking at the patent portfolio of each applicant. All applicants with more than 50 patent applications are retained. A name matching algorithm then identifies companies in Orbis that are potential matches. Each potential match is manually reviewed and linked to a firm when appropriate. In total, 89% of patents in automotive technologies are matched to Orbis.

Following the matching process, the industry and age of firms are adjusted. Large companies in Orbis tend to have several identifiers to refer to different subsidiaries, regions, or businesses. As a result, there are instances where the industry, and/or size of a child company may differ from the parent. For instance, Toyota R&D labs, a subsidiary of Toyota, is labelled as operating in *specialised design activities*. Although Orbis also includes information on the global ultimate owner (GUO), in some cases this information may not be informative on the type of business the firm operates (for instance holding companies).

### *Firm-age*

In this paper, young firms are defined as those that, at the time of application, were 5 years old or younger. The following steps were taken to determine the firm age at application:

- If the firm was matched to ORBIS:
  - The age of the firm at the time of application is obtained by comparing the date of incorporation available from ORBIS with the patent application year. To check for consistency, the date of incorporation of a firm is checked against the patent portfolio of the company. When the earliest patent application of a firm occurs before the date of incorporation, then the date is changed to the earliest patent application year.
- If the firm was not matched to ORBIS, the OECD start-up database is used.
  - The data is matched to firms in the OECD start-up database, also available from the STI MicroData Lab. The age of the firm at time of application is obtained using the same procedure as before.
- If the firm was not matched to ORBIS nor to the OECD start-up database:

The date of incorporation is estimated by looking at the earliest application year of the applicant. Using the information from ORBIS shows that the median age of firms founded after the 1990s at time of their first patent application is 1 year old. As a result, applicants that were not matched to ORBIS nor the OECD start-up database are assumed to be 1 year old at the time of their first application.

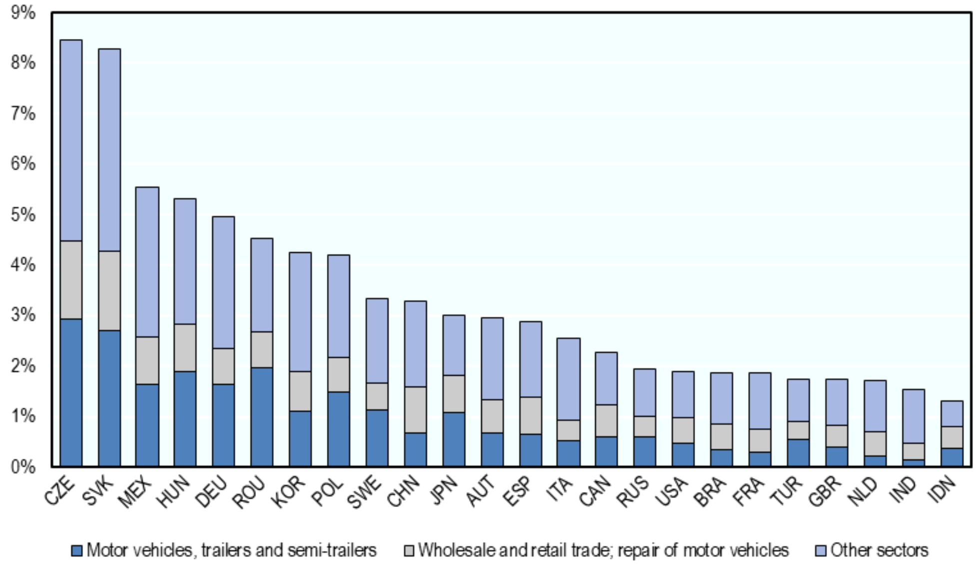
### *Industry*

Firms in the sample are assigned to an industry of operation (International Standard Industrial Classification of All Economic Activities (ISIC), Rev.4) using data from ORBIS. Given that some multinationals and large firms have multiple identifiers in ORBIS — and therefore can potentially belong to multiple industries —the industry of operation of these firms (having multiple ORBIS identifiers and at least 50 patent applications in the dataset) was manually reviewed.

# Annex B. Additional figures

### Figure A B.1. The employment contribution of the value chain is lower than its value added counterpart

Employment embodied in global final demand for motor vehicles, by country and sector, as a share of national employment in 2018




Note: Employment is defined as the number of persons employed – both employees and self-employed. 8.3% of Slovak national value added is embodied in the global final demand for motor vehicles. Among these 8.3 percentage points, 2.7 come from the automotive sector, 1.6 from the wholesale and retail trade and repair of motor vehicles and 4 from other sectors.
Source: OECD, Trade in Employment (TiM) Database, oe.cd/TiVA, February 2022.

# Annex endnote

[1] A total of 6 348 patents are categorised in more than one technology class.