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Abstract

This technical background paper summarises ASCII's initial research into the automotive industry. It lays the methodological groundwork for future research by outlining the methodology used to analyse the automotive industry's transition from internal combustion engines to battery electric vehicles. The method relies on a component-based approach. The analysis focuses on passenger cars, and includes trade specialisation, diversification paths and regional production structures. The bill of materials differs significantly between the two technologies. Electric vehicles are less complex in terms of the powertrain but require more complex electrical energy storage systems. In particular, China has a comparative advantage in almost all EV-specific components, even in segments where few other countries have a comparative advantage. The data support the view that (Upper) Austria is strong in combustion technology. However, the skills required to produce electric vehicles and their components are available, suggesting growth potential for some firms. A product space analysis suggests that electric vehicle technologies are based on a different skill base than combustion engine technologies, making it difficult to diversify from combustion engines to electric vehicles. This has potentially far-reaching implications for policy makers and business decision makers. The research methodology is clearly defined, and its limitations acknowledged. Both the methodology presented, and the initial results form the basis for subsequent policy-relevant research questions. Notably, the component approach hints on production capabilities and does not inform about the quality of the final good.

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Executive Summary

- This technical background paper summarises ASCII's initial research into the car industry, an important part of Austria's manufacturing sector. The industry was chosen due to its economic relevance and its transition challenges. In 2020, the automotive industry alone accounted for about 6% of value added and employment in total manufacturing. Around 40,000 people were directly employed in the industry. Using a broader definition of the industry, including suppliers such as specialised metal product manufacturers, estimates of the value added and employment are around twice as high.
- The car industry is challenged by transformation dynamics that result from the green transition, which may have implications for the competitiveness of wider parts of the economy. The industry is regionally concentrated. Its companies are important local employers in areas such as Upper Austria. Austrian companies are competitive in combustion technologies. It is yet unclear whether the industry is competitive in electric vehicles, and subsequently what transformation processes will look like.
- This report lays the methodological groundwork for future research by outlining the methodology used to analyse the automotive industry's transition. It is based on a component approach to analysing the transition of the passenger car industry from internal combustion engines (ICEs) to electric vehicles (EVs). The bill of materials differs significantly between the technologies. EVs are less complex in terms of the powertrain, even if they require sophisticated electrical energy storage systems.
- The level of analysis broadly shows the competitive positioning. It does not capture complexity possibly incorporated in software or control. In addition, it does not consider intangibles, ancillary sectors (e.g., car repair shops) or the demand side (e.g., mobility concepts). Global trends related to regulations or the greening itself are assumed as given. Also, the component approach does not inform about the quality of the final product.
- The analysis takes a multifaceted approach to the competitiveness related to the production of the components required by either technology. An economy-wide perspective quantifies export competitiveness. A firm level analysis allows for a shift from the global to the regional and eventually to the local perspective. This enables us to focus the lens on Upper Austria. These analyses in this study are based on a variety of data sources. In addition, the team consulted several industry experts.
- An economy-wide analysis of international trade competitiveness shows a mixed picture, with all trading partners having notable strengths in certain product categories. China also leads in exports of EVs and has strengths in ICE production.
- Austria's export portfolio is embedded in the EU and well diversified across the automotive supply chain. It’s firms often cover niche markets, which are represented by the indicator chosen. Its strengths are concentrated in ICE-specific components to a greater extent than in the EU. Even though Austrian companies have export strengths in ICE-specific rather than in EV-specific products, especially Austrian producers that serve niche markets appear to be a notable source of exports for some EV components.
- A product space analysis explores the underlying capabilities and diversification potential. The data shows that there is no single transition path from ICE to EV. Rather, these paths are highly context dependent on the current state of the regional economy and its embedded capabilities. There are fewer and more specific sets of capabilities for EV-specific components than for ICE-specific ones. This has far-reaching implications for policy makers and business decision makers.
- We categorise companies by industry and link them to the wider economic landscape. By retrieving geo-positions, we assign them to regions. A regional specialisation indicator shows that Upper Austria has notable capabilities to produce for EV-specific components. Although the automotive cluster is highly specialised in ICE production, there is potential for alternative regional production structures.
- These findings are mainly based on secondary data analysis and will be further validated and discussed with industry experts. Both the methodology presented, and the initial results form the basis for subsequent policy-relevant research questions.

1. Introduction

The automotive industry is an important part of the EU's manufacturing base. It comprises a complex network of cross-border supply chains involving vehicle manufacturers (OEMs), suppliers and related industries spread across the world. Although organised globally, it tends to be concentrated in geographical regions such as the EU, North America, or Asia, and within these blocs in regions. The industry has undergone constant change (see for instance, Meyer et al. 2021; Wuketich et al., 2022; Sala et al. 2022; Falck et al. 2021). It is currently facing several changes at the same time. These include the introduction of new technologies, changes in the regulatory environment and new foreign competitors. For some parts of the industry, these challenges are increasingly perceived as existential, while others see change as an opportunity for growth.

At the core of the structural change is the transition from vehicles with internal combustion engine (ICE) to electric vehicles (EVs) with electric propulsion as a primary powertrain. EVs are defined as both fully and partially electricity-powered cars: Battery Electric Vehicles (BEVs), Fuel Cell Electric Vehicles (FCEVs) and Plug-in Hybrids (PHEVs) and other Hybrid Electric Vehicles (HEVs). FCEVs are commonly referred to as hydrogen cars because their primary energy source for electric engines is hydrogen. PHEVs and HEVs rely on ICEs for most of their autonomy. The regulation in the EU requires producers to prepare for the phase-out of ICE vehicles and PHEVs (other HEVs as well) by 2035 (Council of the EU, 2022). This study focuses on components for passenger cars and light commercial vehicles.

The Austrian car industry in numbers

These changes may have much wider effects for the manufacturing sector, of which the car industry is an important part of. In 2020, according to Statistics Austria (Structural Business Statistics), enterprises in the Austrian automotive industry itself accounted for about 6% of value added and employment at factor cost in total manufacturing. About 40,000 people were employed in the automotive industry. However, this narrow definition of the industry only includes the manufacture of motor vehicles, trailers and semi-trailers. If the perspective is expanded to include a broader definition of the industry, including direct suppliers such as specialised metal product manufacturers, the estimates of value added and employment approximately double. In Austria, the automotive industry is concentrated regionally, and the companies serve as important employers in local regions, such as Upper Austria. Thus, transformational changes are much more pronounced regionally.

The Austrian car industry is highly internationalised. Not only are production networks spread across Central Europe's manufacturing core and controlled by non-Austrian original equipment manufacturers (OEMs), but also is most of the industry's output is exported, accounting for more than 20% of Austria's total exports. Companies in the automotive sector have made substantial investments in R&D, totalling EUR 100 million in 2020 (SBS, Statistics Austria). This focus on innovation has enabled Austria to maintain its competitiveness in the international automotive market. However, its competitiveness is based on existing technologies, in particular internal combustion engines. It is yet unclear whether the industry is competitive in electric vehicles. It is likely that the car industry is challenged by deep structural transformation dynamics that result from the green transition.

1.1. Aims and limitations of this study

This study aims at quantifying the competitive positioning of firms and regions in the transition from ICE- to EV-specific components. We map the current state of this transition across regions on different levels of granularity, ranging from aggregate, country-level trade data to firm-level information that we portray regionally. We construct profiles for regions that capture the extent to which the automotive industry in this sector currently depends on ICE- or EV-specific components. We thereby hint on elements of a strengths, weaknesses and opportunities, threats (SWOT) analysis of the automotive industry. The research is structured along several guiding questions. How is Austria positioned in international trade? What products are offered by companies in Austria and Upper Austria? What is the location's diversification potential from a product space perspective?

The study is based on a component approach, first identifying stylised components required for internal combustion engines (ICE) and electric vehicles (EV). A third category of components includes items that are needed to produce cars but are not related to the powertrain (e.g. body, tyres).

Of course, this approach has its limitations. It does not aim to provide a comprehensive picture of the car industry. It focuses on supply-side outcomes. It does not discuss how these outcomes are achieved (e.g. regulation, support schemes, co-operation). It does not discuss the demand side (e.g. consumer preferences, consumer incentives, mobility concepts), nor the ancillary industries (e.g. electricity grid, raw material prices).

1.2. The regulatory background

The observed industrial change is largely driven by regulation. Data from the European Environment Agency and the EU show that the transport sector is the second largest emitter of greenhouse gases in Europe. This is also true for Austria. Due to the increase in road transport (measured in terms of kilometres travelled) in the country, emissions from both freight and passenger transport have risen sharply and will be 76% higher in 2020 than 30 years ago (Umweltbundesamt, 2021). The fight against climate change therefore requires the decarbonisation of the transport sector. At the heart of this effort is the transformation of the automotive industry.

Several policy instruments have been introduced to facilitate the 'decarbonisation' of the industry. Directives such as the European Green Deal and the Paris Agreement are pushing the automotive industry towards more sustainable solutions to meet carbon neutral targets. In 2022, the European Commission launched the 'Fit for 55' package (as part of The European Green Deal Directive), which includes numerous proposals to revise and update EU legislation with the aim of reducing emissions by at least 55% by 2030 compared to 1990 levels. This package also includes a proposal to revise legislation on emission standards for new cars and vans, requiring a 55% reduction in average CO2 emissions from new cars between 2021 and 2030 (Council of the EU, 2022). The European Parliament and the Council amended the Regulation on 19 April 2023. The amendment strengthened the emission targets applying from 2030. It set a 100% emission reduction target for both cars and vans from 2035 onwards. It aligned them with the EU's ambition to reach climate neutrality by 2050.[1] Between 2020 to 2024, car fleets are to be reduced to 95 g CO2/km and vans to 147 g CO_2/km (2025-2034 - Cars: 93,6 g CO_2/km (2025-2029) and 49,5 g CO_2/km (2030-2034); Vans: 153,9 g CO_2/km (2025-2029) and 90,6 g CO_2/km (2030-2034). From 2035 onwards, the EU fleet-wide CO_2 emission target for both cars and vans is 0 g CO_2/km, corresponding to a 100% reduction. The Austrian government is also following the recommendation of the Paris Agreement, where the ambition for passenger cars is that 100 per cent of all new car and two-wheeler registrations should be zero-emission by 2030 at the latest (BMK, 2021). In practice, these first steps towards a greener economy in the EU mean that technical solutions for road vehicles will be limited to battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs).

The US, Japan and China have agreed on similar reduction paths. The regulations vary across regions, however. In 2020, China has set a target for new energy vehicles (NEV, which is the Chinese designation for cars that are fully or predominantly powered by electric energy) sales to account for around 20% of total new car sales by 2025 (China State Council, 2020). This target contained in the 14th Five-year-plan Energy Saving and Emission Reduction Work Plan has already been surpassed in 2022. The US has set a nonbinding target for 50% of light duty vehicles sales to be electric by 2030. As a main driver for achieving such a target, the new fuel economy standards have been proposed by the Environmental Protection Agency (EPA, 2023). Some US states, led by California, have set an ambitious target of 100% of light duty vehicles sales to be electric by 2035 (CARB, 2023). The graph below shows historical EV sales shares (solid lines) and regulatory targets (dotted lines) for passenger vehicles in EU27, China and US markets.

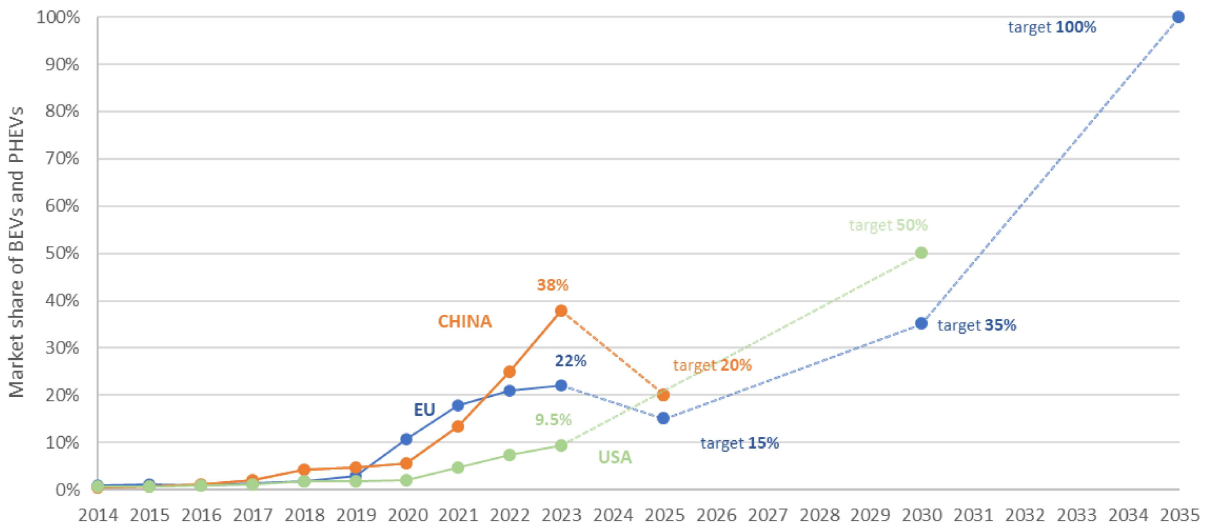

Figure 1: Historical data on market shares of BEVs and PHEVs and regulatory targets for EVs in different jurisdictions.
Note: EVs and PHEVs (solid line) and regulatory targets (dotted lines). Data is taken from the Marklines database and only includes passenger cars.

In addition to regulatory targets, a broad mix of policies and measures is being implemented by many countries across the globe to promote the transition. These include fuel economy standards, CO_2 emissions standards, deployment roadmaps, and sales or stock targets and ambitions.[2] Altogether, this puts pressure on established ICE vehicle manufacturers, which are losing market share to electric vehicle manufacturers. This generates incentives to shift the investment strategy to the development of electric and hybrid vehicles. Automotive suppliers are investing a higher percentage of revenue (0.93%) per year in sustainability than

[1] See https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en .
[2] See https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer.

their OEM counterparts (0.79%) to meet the target of total emissions reduction across the value chain, including Scope 1, 2 and 3 emissions, from sourcing to end-of-life processes (Capgemini, 2022). Suppliers will be challenged to develop new technologies to support EVs and invest in a greener supply chain. To survive in the market, they will need to invest more than ever in new technologies and innovation.

To reduce CO2 emissions from transport, the European Council and Parliament agreed in 2014 to set an average CO2 emission limit value of 95 g/km for 95% of all new passenger cars from 2020 (2021). At the same time, the emission reduction targets for passenger cars and light commercial vehicles for 2025 and 2030 have been tightened by the adoption of revised standards in March 2023 as part of the EU's "Fit for 55" package: the fleet average should not exceed 59.4g CO2/km by 2030. Carmakers that fail to meet these targets will have to pay a fine of €95 per gram of CO2 emitted more than the target for each car sold in the EU. Gradual transitional arrangements until 2023, the possibility of CO2 pooling within group brands, bonuses for particularly environmentally friendly innovations and reduced targets for smaller manufacturers should help carmakers avoid such fines in the short term.

The Euro 7 emissions standard, which includes strict limits on harmful exhaust gases (e.g. unburnt hydrocarbons - HC, nitrogen oxides - NOx) and other emissions (particulates, noise, etc.) in addition to the permitted CO2 limits, will come into force in 2025 and replace the previous emissions standards. These measures, including fines, are intended to accelerate the development of clean transport technologies and decarbonisation.

The CO_2 footprint of electric vehicles relative to combustion engine vehicles

The motivation of this report is to study the transition to CO_2 neutral cars. To meet the emission targets set by EU legislation, the automotive industry is working to improve internal combustion engines and advance vehicle electrification (hybrid vehicles) in the short term. The fleet emission limits imposed from 2021 and especially from 2030 cannot be met by conventional internal combustion engines alone. Hybrid vehicles, especially plug-in hybrids, are seen as a solution that lean towards combustion engines. In the medium and long term, a shift towards electric vehicles and vehicles powered by hydrogen fuel cells or synthetic fuels is essential (Siskos et al., 2015). The underlying assumption is that electric vehicles are less CO_2-intensive than internal combustion engines. This is subject to debate, however. This leads to the question if this assumption holds.

Several studies have compared the CO_2 intensity of electric cars with that of cars powered by internal combustion engines. While most studies argue that electric vehicles emit less CO_2, the technology is not decarbonised, which is why electric vehicles are a transitional technology (see Meyer, Friesenbichler, and Hirz 2021).

When comparing the CO_2-intensity of ICE and EV, a distinction must be made between the production phase and the operation phase. For electric vehicles, producing batteries is CO_2-intensive. In contrast, internal combustion engines emit more CO_2 during the operation phase. The differences in the results of the studies can be attributed to country-specific differences in the energy mix used in production, in the upstream supply chains and in the charging and refuelling infrastructure required. For instance, a battery produced in the EU has lower CO_2 emissions than one produced in China or the US. Equally important, advances in battery manufacturing technologies have made battery production less energy intensive in recent years. Other assumptions relevant to the comparison of electric cars and cars powered by internal combustion engines relate to the operating intensity and durability of the vehicles compared.

The Fraunhofer Institute (Wietschel et al., 2019) argues that greenhouse gas emissions from the production of electric vehicles are 70% to 130% higher than from the production of diesel or petrol vehicles. In operation, electric vehicles would compensate for this disadvantage, with the degree of compensation depending on how the charging current is generated. On average, the lifecycle CO_2 emissions of electric vehicles are around 15% to 30% lower than those of internal combustion engine cars. CO_2 emissions are particularly lower for smaller vehicles, which are better suited to urban driving. On the other hand, electric vehicles with larger batteries, which allow a greater range per battery charge, perform significantly worse, so that the advantage over internal combustion engines is reduced. Studies by the Institute for Energy and Environmental Research (Helms et al., 2018) and Eindhoven University of Technology (Hoekstra and Steinbuch, 2020) come to similar conclusions.

These findings are challenged by a study by the ifo Institute for Economic Research (Buchal et al., 2019). It shows that the CO_2 emissions of an electric vehicle are around 10% higher than those of a comparable diesel car in the best case and more than 25% higher in the worst case. The best result is achieved by a comparable vehicle with a hydrogen-methane-powered internal combustion engine. Its emissions are about one third lower than those of a diesel engine, even after considering the significant emissions in the upstream chain.

Overall, these studies suggest that EVs are less CO_2 intensive than ICEs when considering the entire life cycle of the vehicle (from cradle to grave). However, given current production structures, EVs are not carbon neutral. From this perspective, EVs could also be considered as a transitional technology.

1.3. Demand dynamics

These regulations are reflected by demand patterns. Worldwide, sales of passenger cars and light commercial vehicles increased steadily until 2017 and then slowed down until 2019. Long-term trends are disrupted by the Covid-19 pandemic in 2020, leading to a rapid decline in sales in all regions. From 2020, global car production and sales increase steadily, despite the emerging global supply chain challenges for the automotive industry, such as a shortage of vehicles due to production problems caused by semiconductor shortages or supply chain disruptions following the pandemic. In 2023, global vehicle production reached nearly 83 million passenger cars and light commercial vehicles, a significant increase of 7.8% over the previous year. This increase was driven by positive production trends in all regions of the world, but production levels are still lower than before the pandemic.

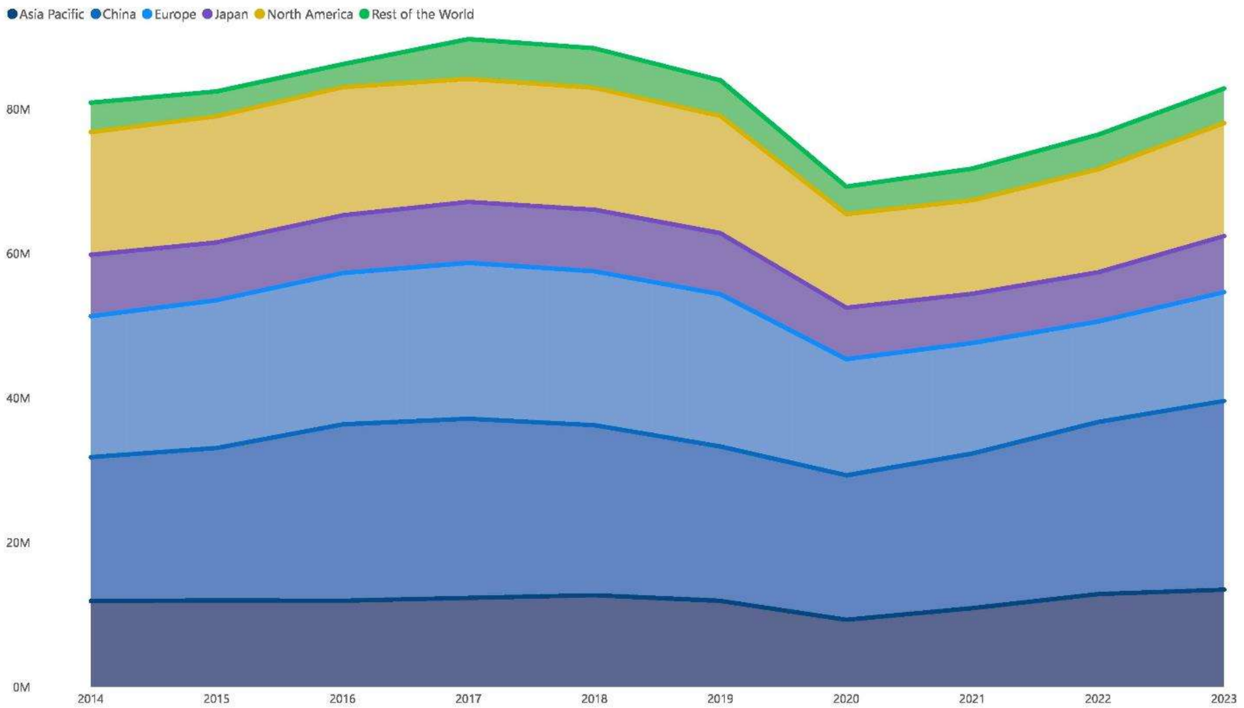

Figure 2: Global production of passenger cars and light commercial vehicles

Source: Marklines

In 2023, China produced more than 26.1 million passenger cars and now accounts for more than a third of the global car production market. The EU consolidated its position as the world's second largest car producer, with production reaching 12.9 million units. The rest of the Asia-Pacific region (especially the Japanese production market) and North America have also seen significant increases in vehicle production in recent years.

A similar pattern can be seen in the number of passenger cars and light commercial vehicles sold in 2023. Worldwide new car sales increase by almost 10% after remaining stable in 2022. Compared to 2022, new car sales in the EU increased by almost 14% to a total of 10.5 million passenger cars. Japanese and US passenger car sales showed robust growth, increasing by almost 16% and more than 14% respectively. In China, passenger car sales grew by 4.5% in 2023, but exports of cars produced there are more significant. At the same time, China was the only major trading partner where EU car exports declined by around 14.4% in volume terms.

China maintained its position as the main source of EU car imports in terms of value. The volume grew by about 37% from 2022. In 2023, its market share amounted to approximately 18%. China, South Korea, Japan, and the UK jointly make for approximately 60% of all extra-EU car imports into the EU. Imports grow fast, raising questions about the competitiveness of EU car producers (acea, 2024).

The recent global shift towards electric vehicles is striking. Global EV sales grew from less than 1% of total vehicle sales a decade ago to more than 14% in 2022. Until 2021, Europe is the largest market in the world, both in terms of the number of EVs sold and the share of EVs in total new car sales. From 2022 onwards, the market share of EVs in Europe starts to stagnate and China is expected to take over the baton, both in terms of the number of EVs sold and the share of these vehicles in the total local market.

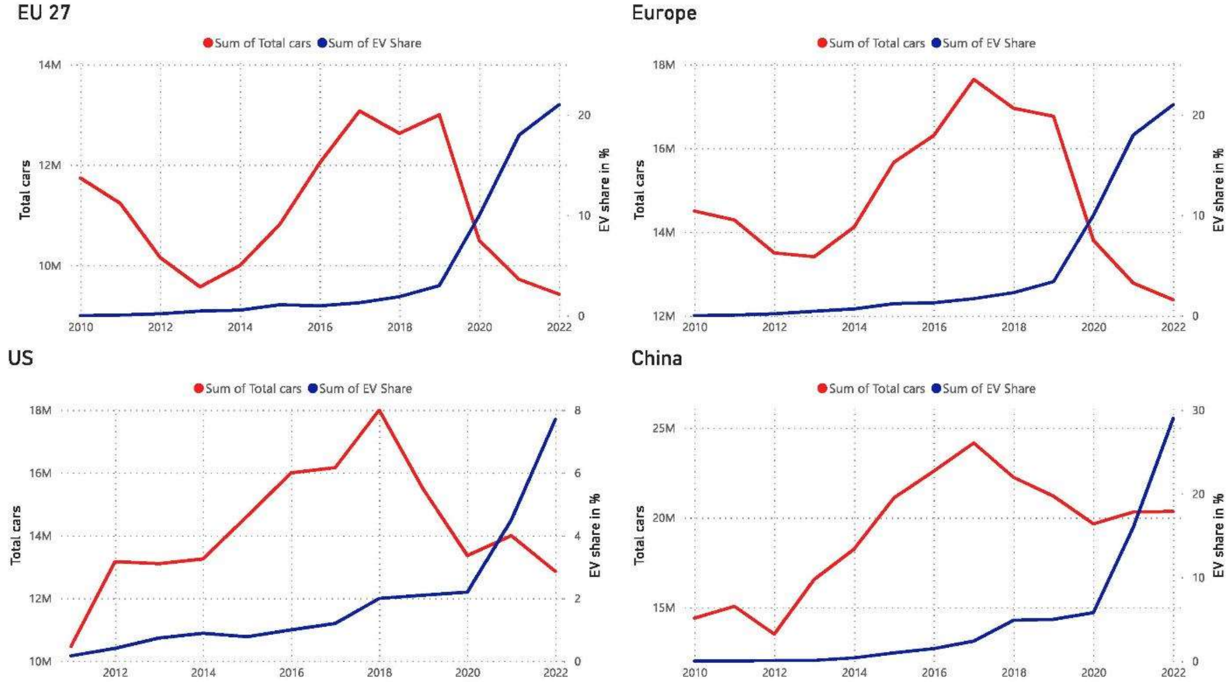

Figure 3: Passenger cars sales and share of EVs on the market by regions.

Source: Marklines and IEA data

So-called "zero emission vehicles" - those powered by an electric motor - are compatible with Green Deal targets (see also box on the CO_2 footprint). At present, PHEVs are also helping to reduce emissions. However, the future of mobility is seen as all-electric, and global competitors seem to have taken this on board. Companies whose product range consists mainly or entirely of electric vehicles. In China and the US, for example, the trend in EV sales is more pronounced than in PHEV sales. Whether or not PHEVs will be part of the transition depends on how quickly traditional carmakers improve the technology so that it can be driven in electric mode most of the time and in most driving conditions (which is not the case today).

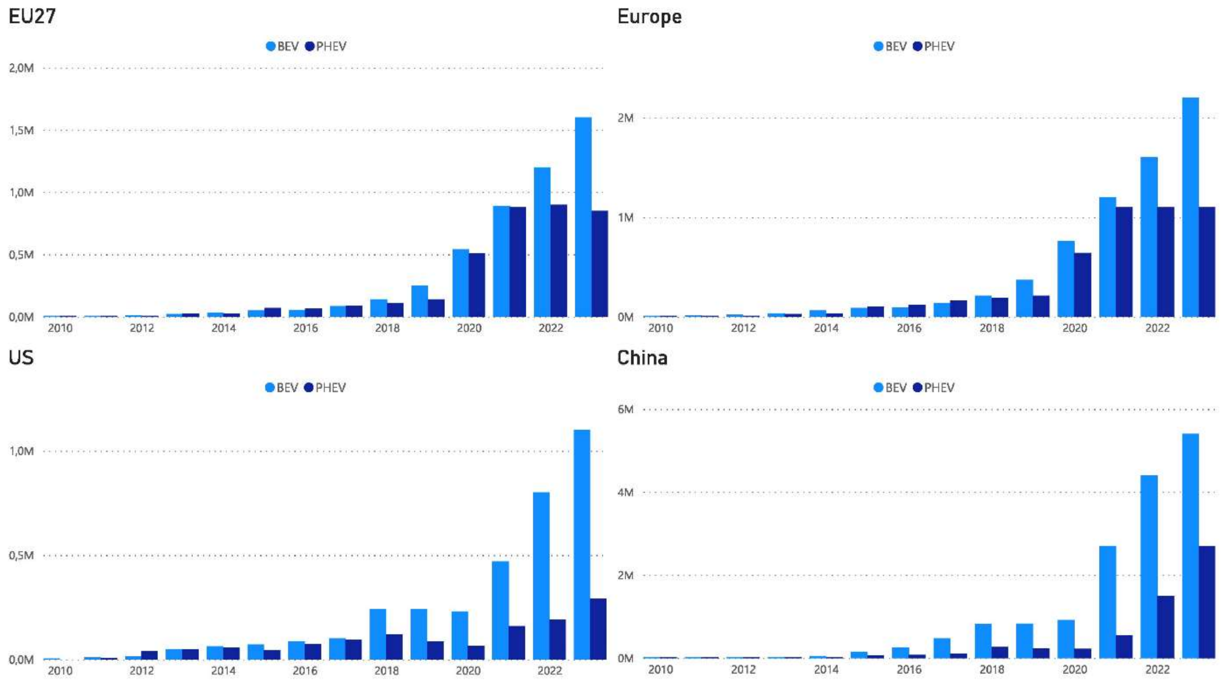

Figure 4: EVs (passenger cars) sales by region

Source: IEA database

2. Methodology

2.1. The component-based approach

This report uses a component-based approach to comprehensively map the state of play in the transition from internal combustion engines to electric vehicles. The main data source is the Marklines supplier database, a widely established information platform about the car industry. We have extracted information on 62,198 different companies in 86 countries for 921 products (components).[3] This data contains a hierarchical categorisation of components, see Figure 5. For example, connecting rods (third category) are part of the engine structure (second category), which is part of the engine (main category). These components are further linked to standardised product codes as provided in the "Harmonized System" (HS) codes which allows us to link this information to trade data, such as the BACI data.[4]

Main Category	Second Category	Third Category	Sub-components
☐ Engine	☐ Engine Structure	☐ Cylinder Block	
		☐ Cylinder Liner	
		☐ Cylinder Head	
		☐ Cylinder Head Cover	
		☐ Cylinder Head Gasket	
		☐ Cylinder Head Bolt	
		☐ Piston	
		☐ Piston Ring	
		☐ Piston Pin	
		☐ Connecting Rod	☐ Connecting Rod Bolt
			☐ Connecting Rod Bush
		☐ Crankshaft	

Figure 5: Product-tree structure extracted from Marklines.

We develop a taxonomy of components for the automotive industry. We define three component groups to assess the competitiveness during the transition:

- Components that are technology-independent with respect to ICE or EV (unspecific), such as tyres or the bodywork,
- Components that are only required for EV but not for ICE (EV-specific),
- Components that are only required to produce ICEs (ICE-specific).

The components which are required for electrical driving are considered, regardless of the type of car. Similarly, hybrids are viewed as a transition technology, whose components are split to both categories and mostly allocated to ICEs. Overall, they represent a small proportion of the total component list and do not change the overall picture significantly.
These component lists enable a straightforward analysis of international competitiveness. The product codes allow us to compute the revealed comparative advantage (RCA). This indicator uses international trade flows (trade values) to show the relative advantage or disadvantage of a certain country in a certain class of goods. Hence, we are able quantify and compare the relative trade competitiveness of China, the EU, the US, and Austria as producers of ICEs and EVs.
Next, we seek to understand how transition paths from ICE to EV might look like on a firm-level basis. It is unlikely that such a transition will be linear in the sense that a company producing certain ICE-specific components can easily replace this component by manufacturing the EV-specific substitute. Rather it might be the case that the skills and capabilities needed to produce ICE-specific components could preadapt the company to diversify into a completely different industry where similar skills and capabilities are required.

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[3] For the product space analysis (see below)- gci and gcp its 917 products since we excluded 4 products which only statistically significantly correlate with each other
[4] See https://www.marklines.com (accessed on 8th April 2024).

Similarly, the paths toward the production of EV-specific components are likely not originating from the manufacture of ICE-specific parts but might also come from other industries. To better understand these transition paths, we chart the product space of automotive components and try to identify how EV-specific components are accessible in this space.

2.2. Internal combustion engines and electric vehicles

From the Marklines dataset we extracted 62.198 distinct firms in 86 countries for 921 products.[5] We categorised these products into those specific to electric vehicles (EV), internal combustion engines (ICE) and those that are unspecific and therefore used in both. From these 921 products, we find that 74542 are unspecified components (used in both ICE and EV), 232 are ICE specific and 74 are EV specific. In short, the component approach suggests that electric vehicles are less complex in terms of the powertrain but require more complex electrical energy storage systems.

We have expanded upon the classification of automobile components to create a distinctive product space. In this space, the relationship between each pair of car parts is assessed based on the concept of proximity. By analysing the topology of this product space, we can infer feasible transition routes from internal combustion engine (ICE) vehicles to electric vehicles (EVs).

This distinction between EV, ICE and unspecific was also applied to the mapping of CN goods codes when the CN codes for individual vehicle components identified from the Combined Nomenclature 2023 coding system were allocated to the relevant categories.

In conjunction with the development of vehicle component lists, it was imperative to comprehend the nature and function of each vehicle component. This understanding was crucial because the description of a vehicle component serves as the primary identifier for the traded commodity. It is essential that the description of a vehicle component aligns with the commodity description in a trade coding system, ensuring semantic consistency, and matches the relevant CN (Customs Nomenclature) code. For example, the vehicle component "Fuel cell" in the component list should be categorized under CN code 8501 31 34, described as "DC generators of an output exceeding 375 kW."

This methodology also entailed cross-referencing web-based information obtained from previous classification repositories of similar products. Nevertheless, all matched CN codes required validation by an expert before finalizing the list.

The identified companies were geo-located and assigned to industrial classifications. This allows the companies in the automotive supply chain to be placed in an overall economic context.

2.3. Measuring International trade competitiveness

Trade data

Based on trade data, we ask which are the main world regions that are exporters of EV, ICE, and unspecific components. The analysis departs from raw data from the United Nations Comtrade database that aggregates detailed global annual and monthly trade statistics by product and trading partner for use by governments, academia, research institutes, and enterprises. Data compiled by the United Nations Statistics Division covers approximately 200 countries and represents more than 99% of the world's merchandise trade. This data is used in the BACI dataset, which builds on the trade data from the United Nations Statistics Division Comtrade dataset. BACI was used because countries in the raw trade data may contain duplicates since trade from country *i* to country *j* may be reported by *i* as an export to *j* and by *j* as an import from *i*. The reported values should match in theory. In practice, however, they are virtually never identical, for two reasons: First, import values are reported including cost, insurance, and freight (CIF) while exports are reported as free on board (FOB) values. Second, discrepancies in the classification of a certain product between the exporting and importing country. Hence, BACI data is used because it provides a unique, reconciled trade flow by implementing a harmonization procedure to mitigate those issues by estimating transport costs (CIF costs) and removing them from import values to compute FOB import values. In addition, the reliability of each country as a reporter of trade data is assessed. If a reporter tends to provide data that are very different from the ones of its partners, it will be considered as unreliable and will be assigned a lower weight in the determination of the reconciled trade flow value. 6

The report is based on the “Harmonized Commodity Description and Coding System”, commonly referred to as the "Harmonised System" or simply "HS". It is a multi-purpose international commodity nomenclature developed by the World Customs Organisation (WCO). It comprises more than 5,000 commodity groups, each identified by a six-digit code, arranged in a legal and logical structure, and supported by well-defined rules to achieve uniform classification. Individual products are available at the more detailed eight-digit level.

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[5] Cognisant that distinguishing between “finished products” and “components” is in some cases difficult, this analysis focuses on components. The level of granularity is given by the data structure.

[6] See https://comtradeplus.un.org/ and http://www.cepii.fr/cepii/en/bdd_modele/bdd_modele_item.asp?id=37 (accessed on 8th December 2023).

The classification in "digits" bins products into commodity groups. The higher the digit, the higher the level of disaggregation. In the present setting, this raises the question how parts are considered at the lower level. At the very granular level (e.g., HS 8-digit), each component is assigned to an HS code, regardless the complexity or composition of the component. Hence, both single components (e.g., engine parts) and semi-finished and finished products (e.g., engines) which contain these components are considered in the statistical system.

An indicator of trade competitiveness

In addition, calculating the revealed comparative advantage for each internationally traded automotive product can provide insights into the country's specialisation and competitiveness in specific areas of the automotive value chain. The revealed comparative advantage (RCA) indicates the degree of specialisation and international competitiveness in the production of a given product. The RCA is calculated as the ratio of a country's share of world exports of a specific product to its share of world exports of all products. We consider a symmetric version of the Balassa RCA index, i.e. $\mathrm{RCA}_{\mathrm{ip}} = \left(X_{ip}/\sum_i X_{ip} - 1\right)/\left(\sum_{\mathrm{p}} \mathrm{X}_{\mathrm{ip}}/\sum_{\mathrm{i}}\sum_{\mathrm{p}} \mathrm{X}_{\mathrm{ip}} + 1\right)$, where X_{ip} are the exports of country i of product p. For the calculation of the RCA, a product is defined at the 6-digit HS level for which detailed country product level trade flows are available.

Since the automotive components are classified at HS 8-digit level, the exports are weighted according to the occurrence of the classified component at the 8-digit product level within the 6-digit product code. For the categorization as EV, ICE, or unspecific products, only the respective EV, ICE or unspecific component share within the product group is considered in the weighting scheme. In total, there are 21 HS codes at the 6-digit level, which contain EV components, 44 HS codes at the 6-digit level that contain ICE-specific components and 88 HS codes at the 6-digit level that contain components which are unspecific, i.e. used in EVs as well as ICEs.

The RCA ranges between -1 and 1, with a value close to -1 indicating a comparative disadvantage and a value close to 1 a comparative advantage. If a country has a revealed comparative advantage in a particular product (i.e. $RCA > 0$), the country is a competitive producer and exporter of that product compared to a country that produces and exports the same good at or below the world average. A country with a revealed comparative advantage in a particular product is considered to have export strength in that product. The higher an economy's RCA for a product, the higher its export strength for that product.

2.4. The product space and green complexity

We use the firm (f) - product (p) data from the Marklines dataset to compute a measure of proximity ($\phi_{pp'}$), connecting pairs of products. This quantifies how closely related different products are based on the firms that produce them. It is defined by the minimum conditional $\phi_{pp'} = \sum_f M_{fp} M_{fp'} / \max\left(M_p, M_{p'}\right)$ probability with M_{fp} being the binary firm product specialization matrix. This yields the so-called "product space", where products are positioned based on their similarity (proximity) to each other. The relatedness density $w_{fp} = \sum_{p'} M_{fp}\, \phi_{pp'} / \sum_{p'} \phi_{pp'}$ quantifies the fraction of related products produced by a firm.

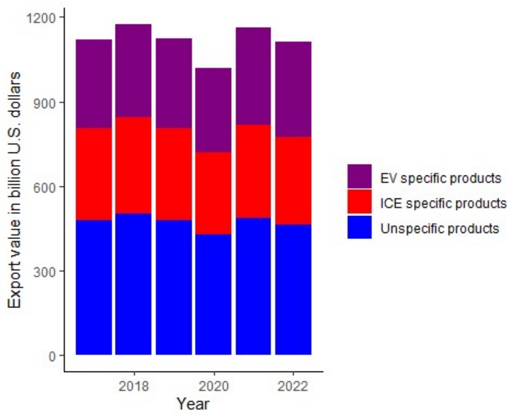
The Product Complexity Index (PCI) is a metric to quantify the diversity and sophistication of products produced by a firm (Hidalgo et al. (2021)). We follow the approach of Mealy et al. (2022), who combine the product complexity methodology with product lists that capture "green" or environmentally friendly products. This provides a proxy for green production capacity and green export potential. We therefore apply this methodology to the automotive industry and calculate the average Green Product Complexity (GPI) per country by combining the PCI with information on EV specialisation to assess how well countries produce advanced EV-related products. By factoring in both GPI and related density w_{fp} to compute the mean green complexity potential (GCP) per country, we gain insights into a country's potential to expand in the EV industry.

3. Results

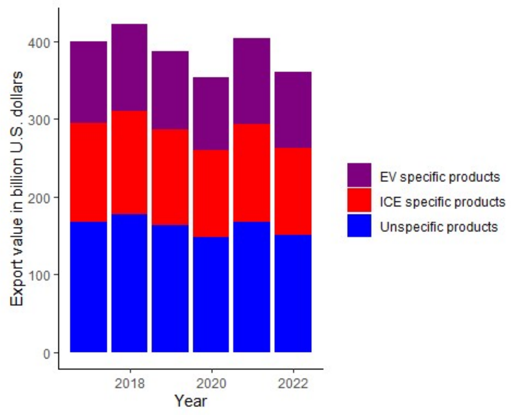
3.1. International trade competitiveness

Export dynamics

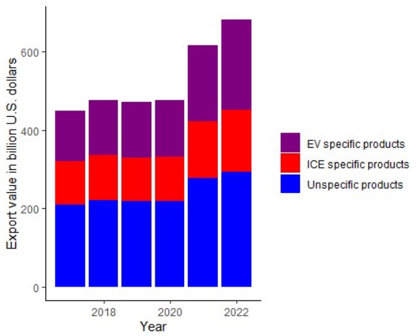
Based on this reconciled international trade data, Figure 6 shows the development of ICE- and EV-specific products as well as unspecific category of products. While the EU and the USA have a high share in ICE-specific components in their export basket, Chinese international trade is dominated by EV specific products. Most of the automotive EU trade takes place within the EU value automotive value chain, dominated by trade in automotive parts with Germany. While Extra-EU exports show a declining trend, China's dominance in EV specific automotive parts is growing worldwide.



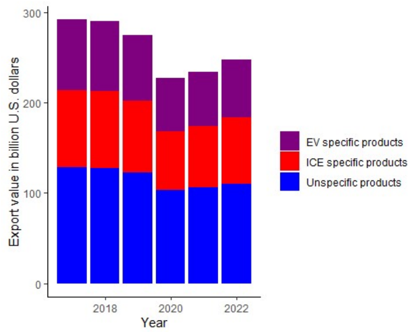
(a) EU (incl. intra-EU trade)



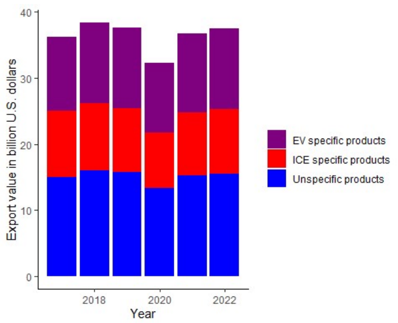
(b) EU (excl. intra-EU trade)



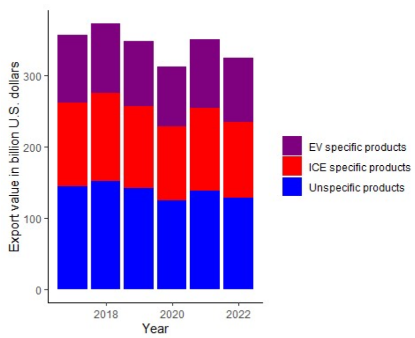
(c) China



(d) USA



(e) Austria

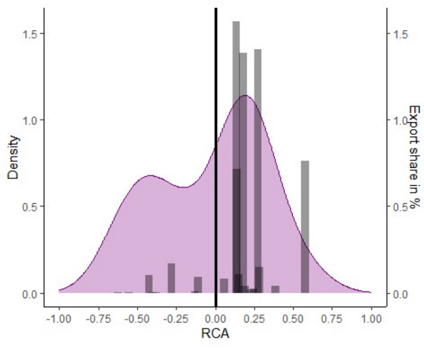


(f) Germany

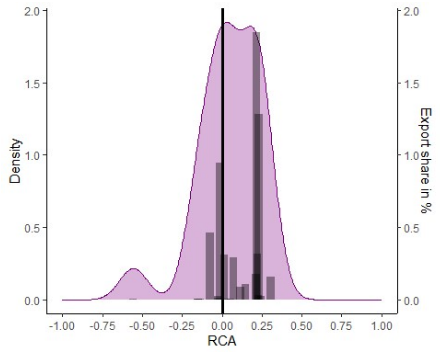
Figure 6: Development of export values from 2017 to 2021 (real, GDP deflator, base year 2015)

Trade competitiveness in EVs

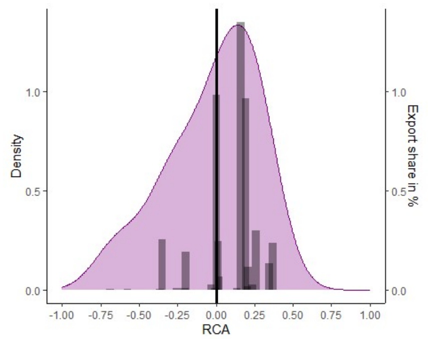
Figure 7 shows the distribution of RCA values in EV-specific products in 2021 for (a) Austria, (b) the EU, including trade within the EU, (c) the EU, excluding intra EU trade, (d) the US, (e) China and (f) Germany. Looking at the mode of these distributions (most frequent values in the histogram), Austria has for some selected products a comparative advantage in EV-specific products (see Appendix for a product list). The mode shifts progressively to the right from the US, from Austria to the EU driven by Germany, and from Germany to China. Although Austria has a lower export strength than the EU for most components, for some categories Austria has a significant export strength with RCA values larger than 0.5. Note however, that this strength is in a relatively category in which the trade share is relatively low. Hence, the category takes a minor role in terms of trade volumes. This is also true for the EU and Germany, which display a high export strength in some product categories, the export share of those is compared to the ones of the United States and China relatively small.



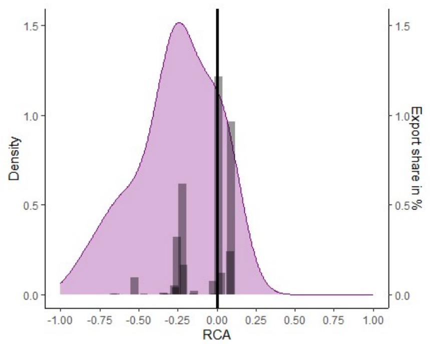
(a) Austria



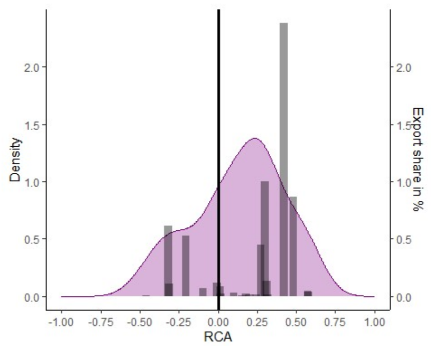
(b) EU (incl. intra-EU trade)



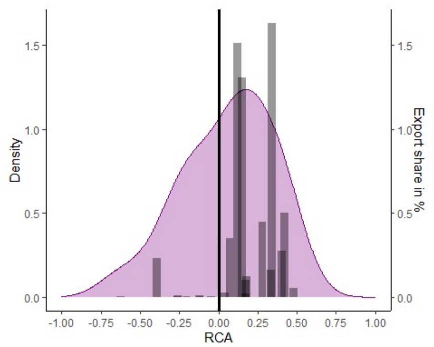
(c) EU (excl. intra-EU trade)



(d) USA



(e) China

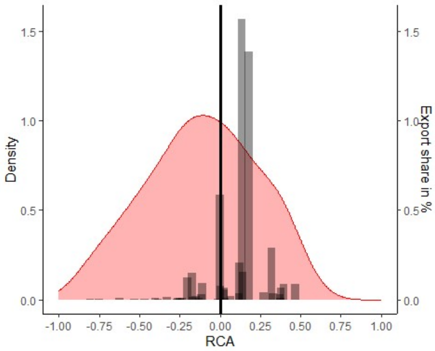


(f) Germany

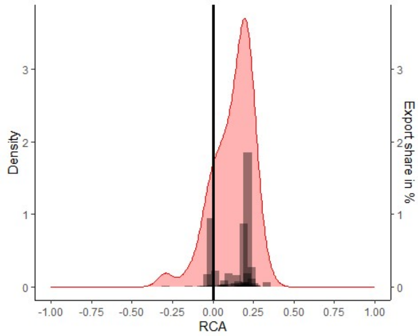
Figure 7: Revealed comparative advantages over EV-specific products and corresponding product group specific export shares of the respective EV-specific products in 2021.

Trade competitiveness in ICEs

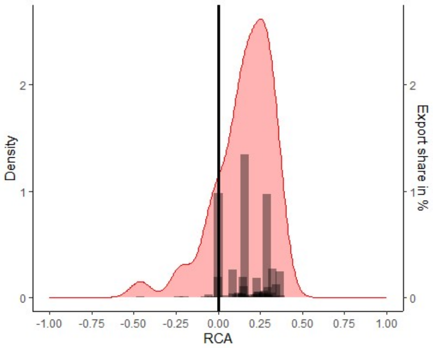
Figure 8 shows the RCA distributions for ICE-specific components for Austria, the EU, the United States and China. Austria is mainly strong in the export and production of ICE-specific products. Austria clearly has more export strengths in ICE-specific products than in EV-specific products. China, on the other hand, has an overall lower RCA ranking than the US and the EU.



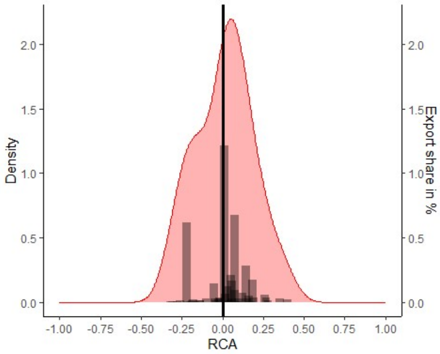
(a) Austria



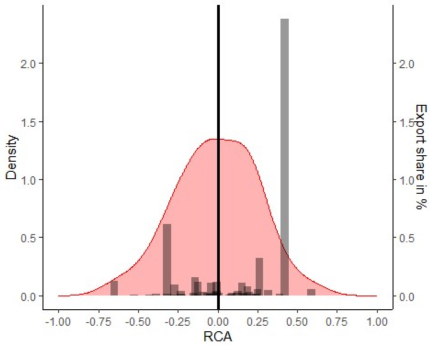
(b) EU (incl. intra-EU trade)



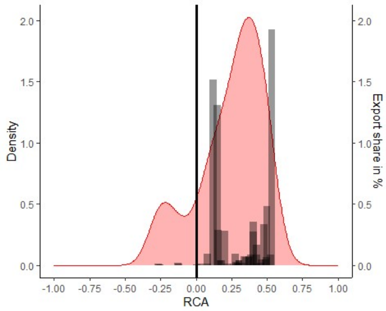
(c) EU (excl. intra-EU trade)



(d) USA



(e) China

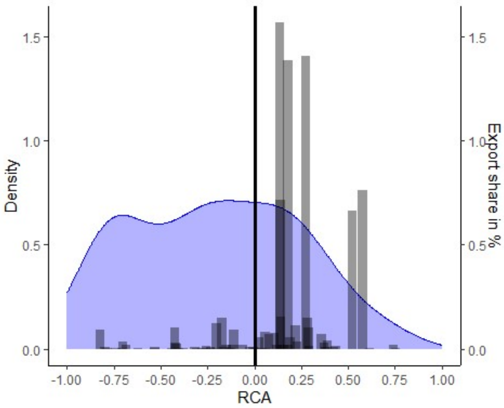


(f) Germany

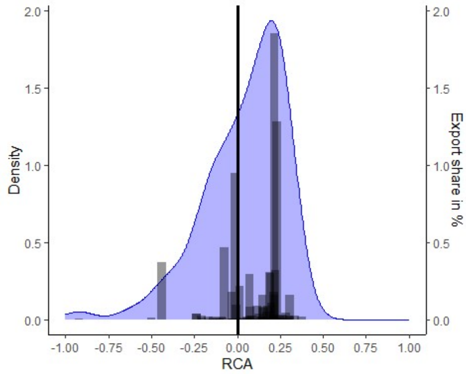
Figure 8: Revealed comparative advantages over ICE-specific products and corresponding product group specific export shares of the respective ICE-specific products in 2021.

Trade competitiveness in unspecific components

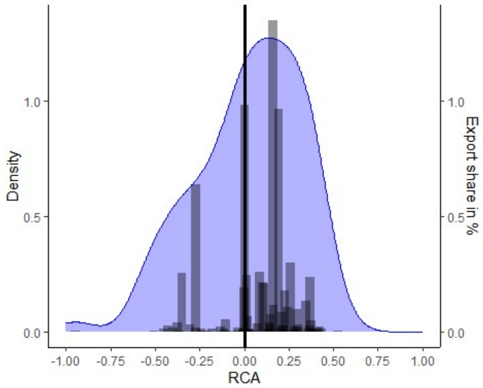
Figure 9 completes this part of the analysis, showing RCA values for unspecific components in the four regions. The EU, China and the United States show similar distributions centred around RCA values of one. Austria shows substantially lower values unspecific components compared to ICE-specific components.



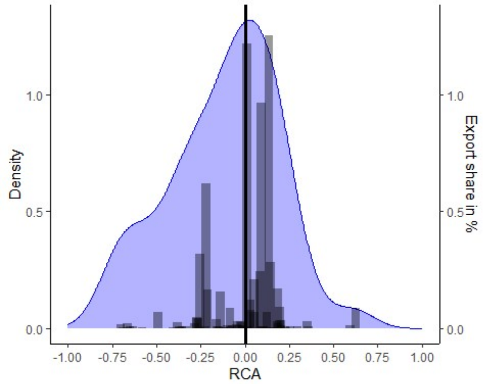
(a) Austria



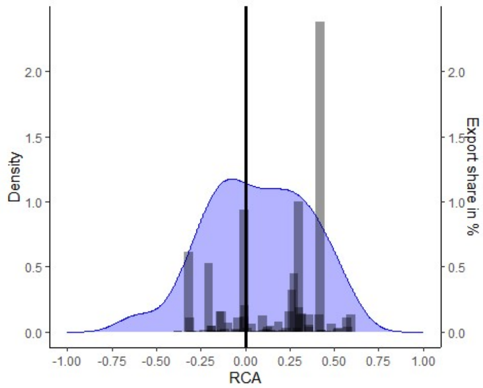
(b) EU (incl. intra-EU trade)



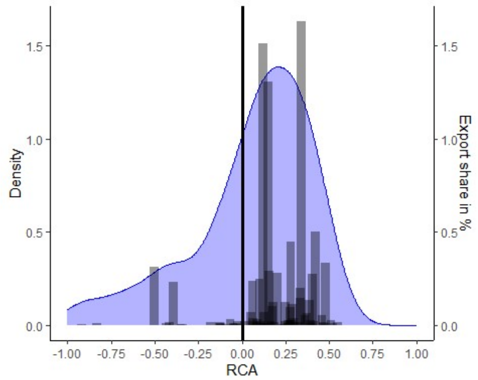
(c) EU (excl. intra-EU trade)



(d) USA



(e) China



(f) Germany

Figure 9: Revealed comparative advantages over unspecific products and corresponding product group specific export shares of the respective unspecific products in 2021.

Trade competitiveness across countries

The heatmaps shown in Figure 10, Figure 11, and Figure 12 provide the distribution of RCA values for EV-, ICE-, and unspecific components across countries. Comparing the density of export strength among different EV specific products in Figure 10 reveals that particularly China has a comparative advantage in nearly all EV specific components like permanent magnets needed for AC and DC motors (included in product code 850511) and EV climate control parts (included in product code 851629). Particularly, China also has an export strength in EV-specific components, in which not many other countries have a comparative advantage. Austria, despite focusing traditionally more on ICE-specific components, also has a strength in the production of few EV-specific components like e-axle (included in product code 870850), heat pump systems for climate control parts (included in product code 841581) or winding wire for electrical purpose or types of DC motors or AC motors (included in product code 850151).

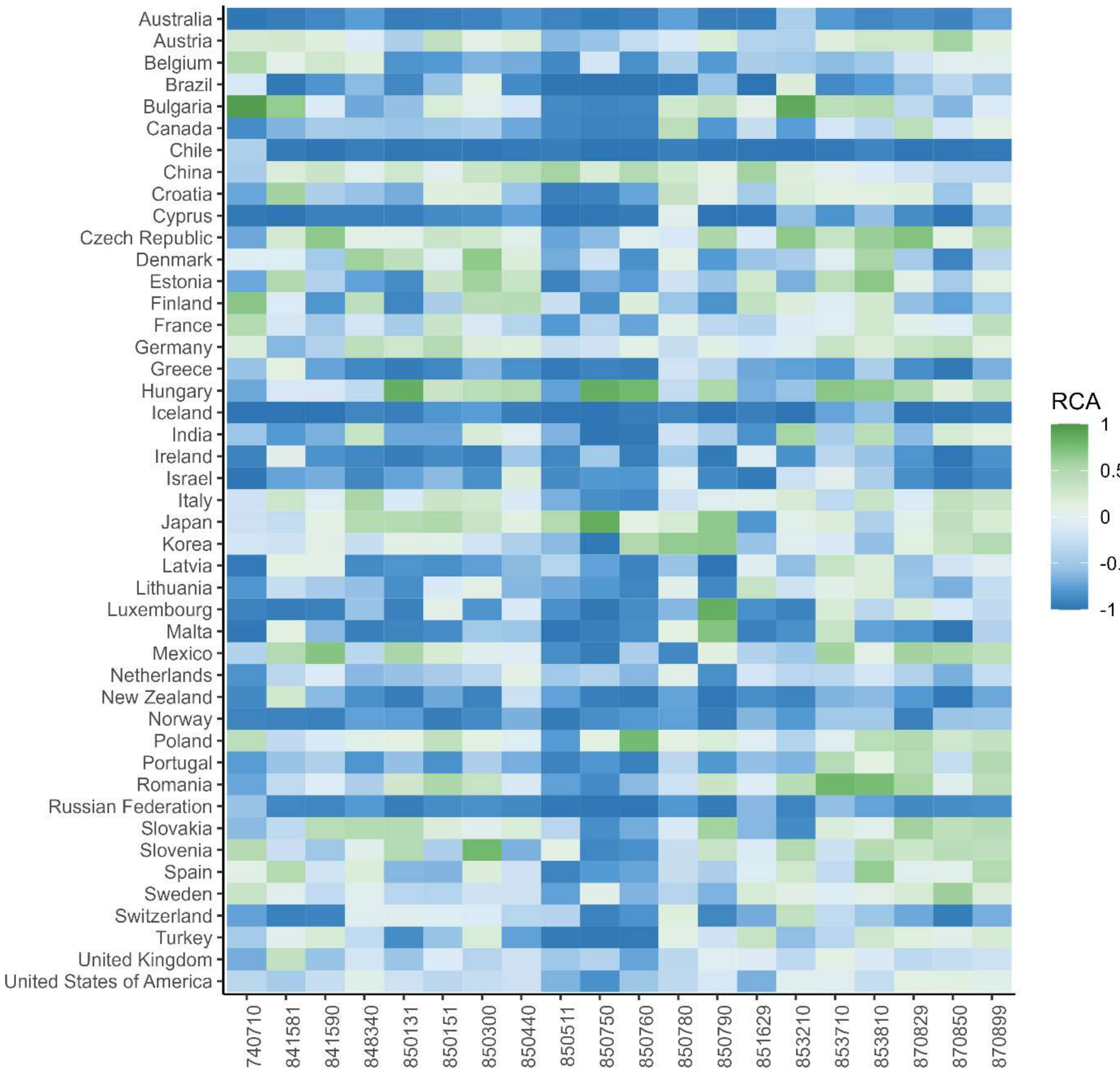


Figure 10: RCAs for the 20 most traded EV-specific products for selected countries (EU + OECD + BRICS) in 2021.

The heatmap in Figure 11 shows the distribution of RCA values ICE-specific components. The economies, which are traditionally known for their strong automotive industry, like Germany or the United States, reveal a strong comparative advantage in all ICE-specific components. These countries also have a strong automotive supply industry, nearby which becomes visible when looking at the comparative advantage revealed by the export strength of ICE-specific components and unspecific components of neighbouring countries. While Austria displays a strength in some ICE-specific components, other countries like Slovenia or Slovakia are more focused on components needed in ICEs and EVs (see Figure 12).

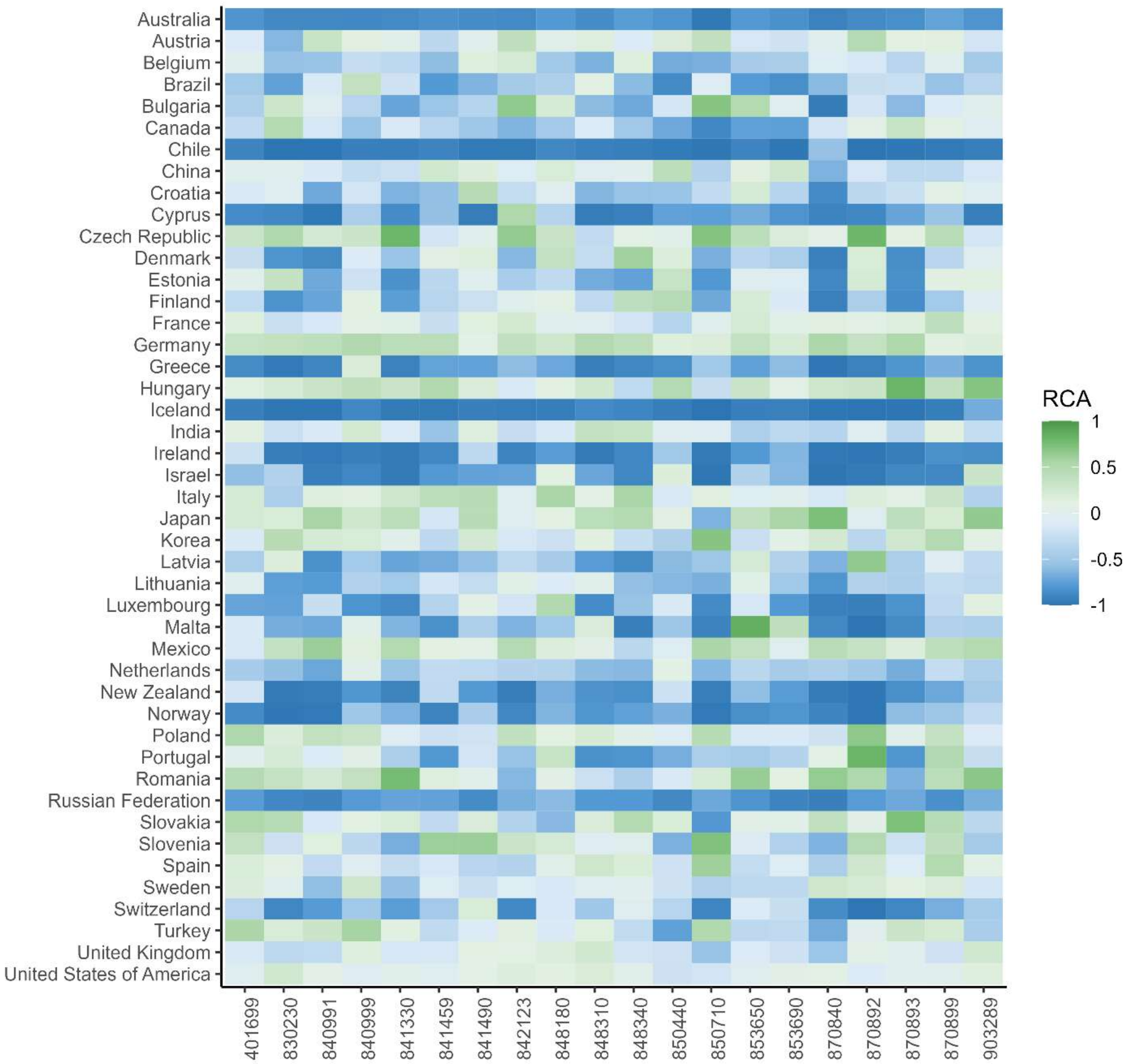


Figure 11: RCAs for the 20 most traded ICE-specific products for selected countries (EU + OECD + BRICS) in 2021.

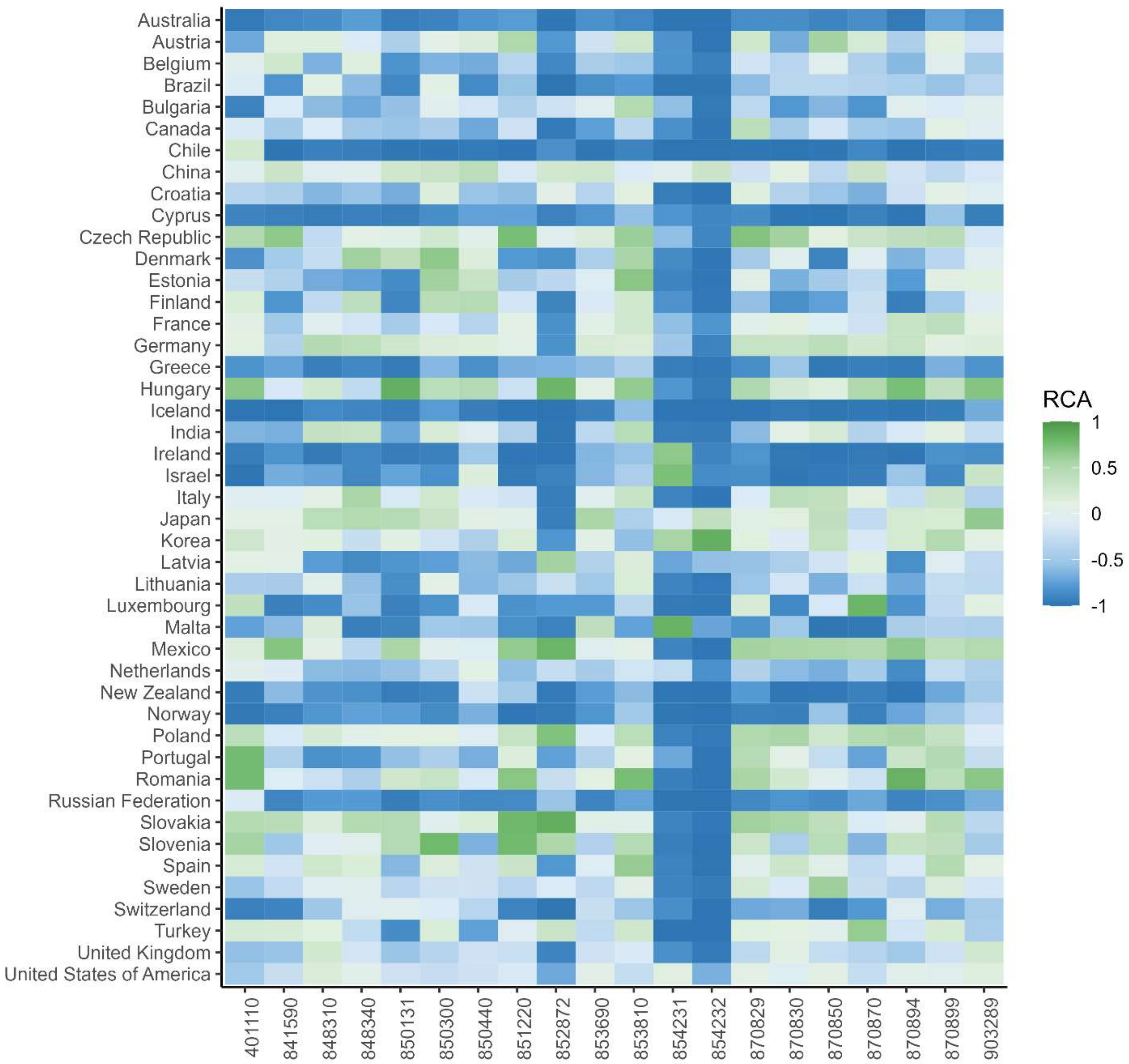


Figure 12: RCAs for the 20 most traded unspecific products for selected countries (EU + OECD + BRICS) in 2021.

In summary, Austria's export portfolio is well diversified across the automotive supply chain. However, these strengths are concentrated in ICE-specific components to an even greater extent than in other car component producing EU Member States. Overall, China is stronger in exports of ICE-specific components than the US, which is stronger in these components than the EU. These results appear to be relatively stable over the observation period considered. This suggests that, despite the increase in EV production, there has been little movement in these relative positions since 2017.

3.2. Towards a mapping of transition paths

A transition is a departure from the status quo. This naturally raises the question of whether change is path dependent and can be managed. The first step is to understand how car components are interrelated and how current specialisation can be used in the future. To do this, we have developed a product space as a first step. Note that we exclude four of the 921 products because they do not correlate significantly with other products.

The blue nodes represent non-specific products, the red nodes represent ICE-specific products, and the purple nodes represent EV-specific products. From the topology of this product space, we can draw conclusions about realistic transition paths from ICE to EV. Regions or clusters in the product space are often associated with different sets of skills required to produce the products in a cluster. If several products require similar skills, knowledge base, infrastructure, or other prerequisites, it is increasingly likely that firms will be able to produce them together, creating a link between them in the product space. If this is true for several products at the same time, we get a cluster.

We observe that the EV-specific products are clustered in the network, i.e. the purple nodes are often found near each other. Thus, the product space has a distinct and clearly definable region of EV components. There are also well-defined clusters of ICE-specific components, but some of these components are also scattered throughout the network and do not cluster in the network.

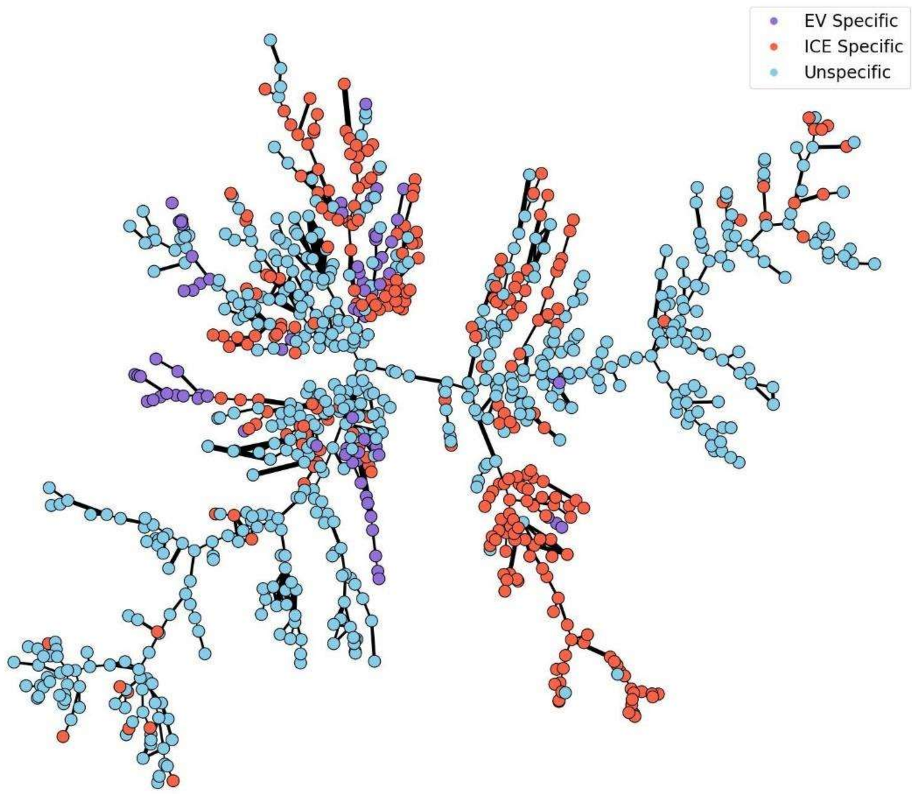


Figure 16 - The automotive supply chain product space (EV and ICE), derived from 917 products in the Marklines database.
Note: Blue nodes represent unspecific products, red nodes represent products specific for ICE and purple nodes represent products specific to EV.

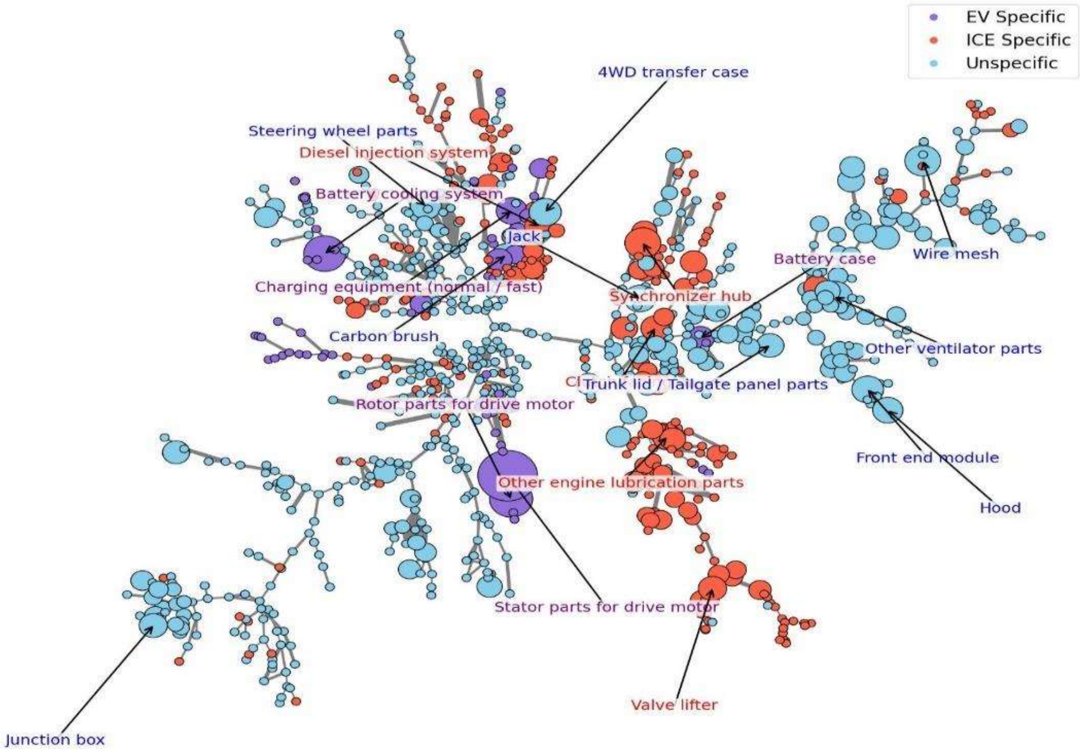


Figure 17: The automotive supply chain product space (EV and ICE).
Note: Blue nodes represent unspecific products, red nodes represent products specific for ICE and purple nodes represent products specific to EV. Here, the node sizes are proportional to the specificity per product of Austria relative to the global market.

The product space therefore suggests that there are fewer and more specific of such capability sets for EV-specific components than for ICE-specific ones. In other words, our analysis clearly shows that there is no unique transition path from ICE to EV. Rather, these paths are highly context-dependent on the current state of the regional economy and its embedded capabilities.

Knowledge of this product space enables us to chart such possible transition paths for different regions based on their strengths. Following the approach of Mealy et al. (2022) we compute the green complexity index (GPI) to quantify the extent to which countries competitively produce technologically intricate EV-specific products. The GPI and GCP are presented in Figure 19 figure for different countries. We find highest mean GCI for the United Kingdom, Canada, Korea, China, and Italy and the highest mean GCP for the United Kingdom, Canada, Austria, Italy, and Korea. The average log GCP values for firms in Austria stand at 2.01 (standard deviation = 0.77). Specifically, in Upper Austria, the average log GCP value is 1.88 (standard deviation = 0.39), while across all other federal states, the average GCP for firms is 2.11 (standard deviation = 0.95)

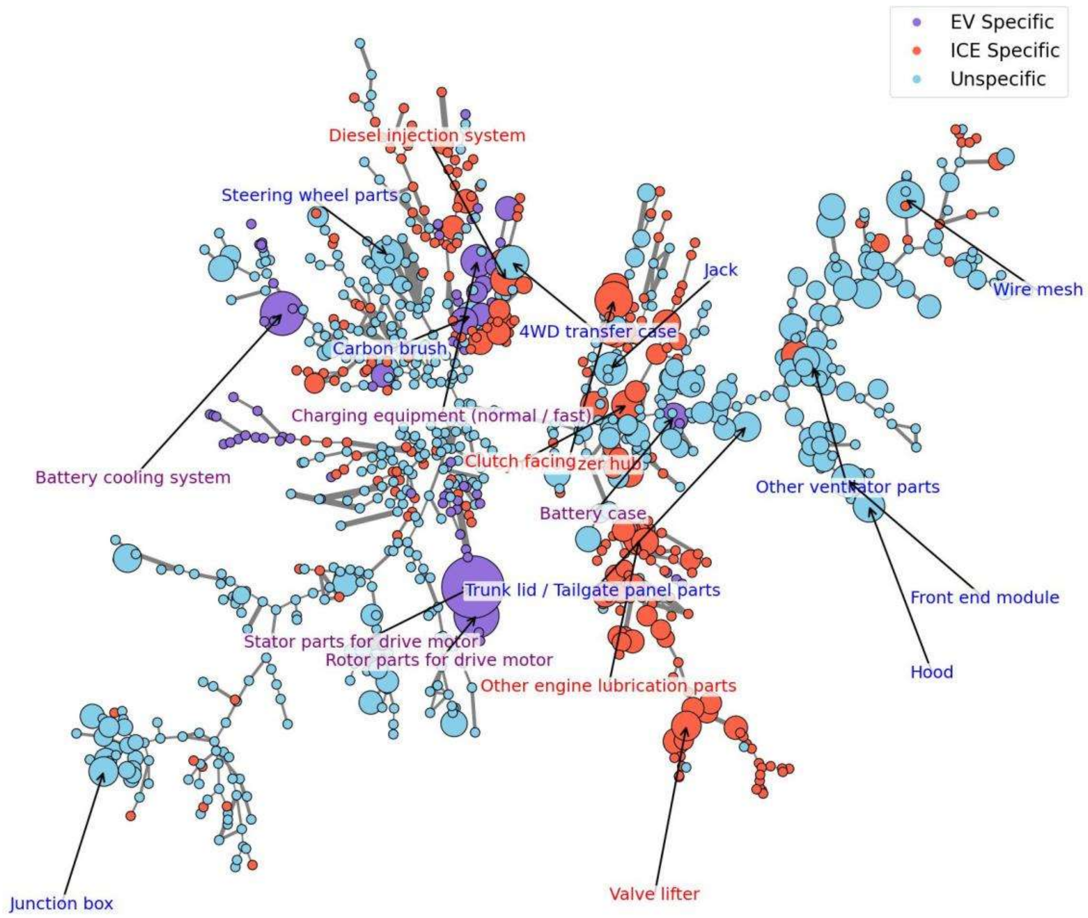


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Figure 18: The automotive supply chain product space (EV and ICE).
Note: Blue nodes represent unspecific products, red nodes represent products specific for ICE and purple nodes represent products specific to EV. Here, the node sizes are proportional to the specificity per product of Upper Austria relative to the global market.

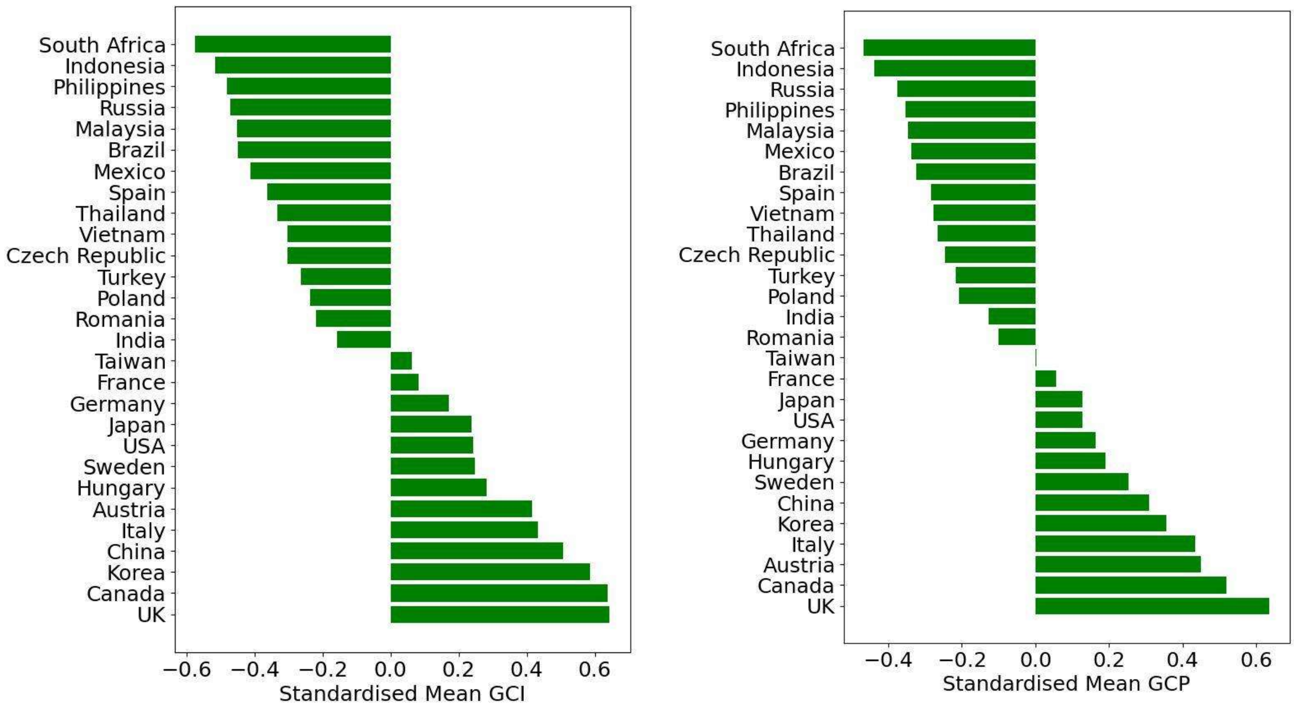

Figure 19: Mean Green complexity index (GCI) per country (left) and mean green complexity potential (right) per country.
Note: For countries with 250 firms or more.

3.3. Analysis at the firm level

We now inquire whether an analysis at the firm level yields similar results compared to the trade data. This analysis allows to substantially increase the granularity of the results, from less than 50 regions to about 63,000 companies and from slightly more than 30 product categories to more than 800 components. The firm-level information is drawn from the Marklines dataset.

Figure 13 provides descriptive information on the data. Most companies in the dataset are specialised in a handful of components whereas only few companies can produce more than 100 different components (note the logarithmic scaling of the y-axis in the figure). Similar observations hold for the distribution of the number of firms per product. Most products are made by few firms whereas a small number of components are produced by several thousand companies.

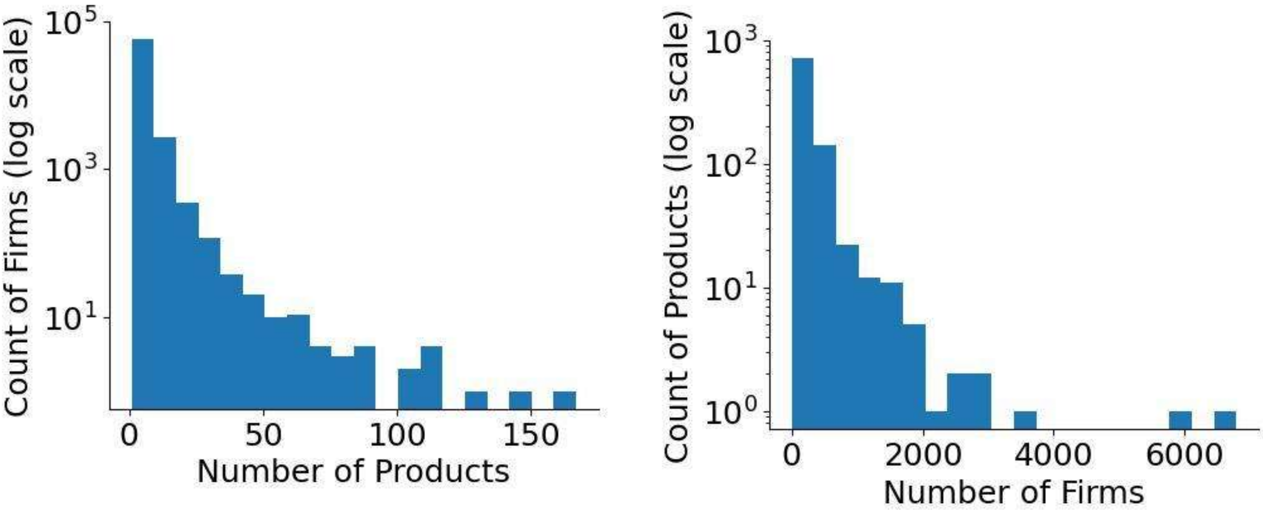

Figure 13: Distribution of number of products per firm in the entire dataset and distribution of number of firms per product.

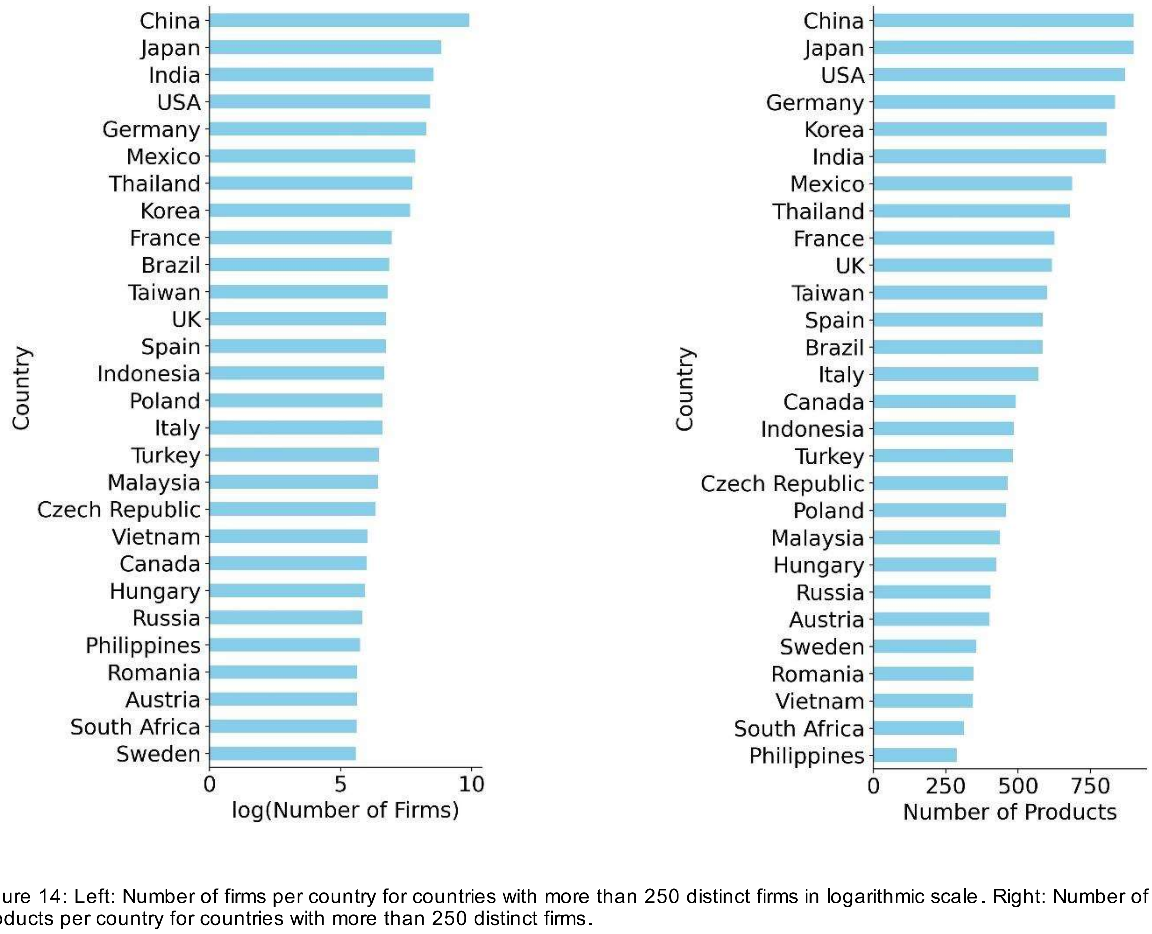

Figure 14: Left: Number of firms per country for countries with more than 250 distinct firms in logarithmic scale. Right: Number of distinct products per country for countries with more than 250 distinct firms.

Figure 14 shows the number of different firms and products per country. China, Japan, India, USA, and Germany make up the list of the five largest countries in both cases. Austria ranks slightly higher in terms of the number of products compared to its number of firms, suggesting that its companies produce on average more different components than other countries with a comparable number of firms.

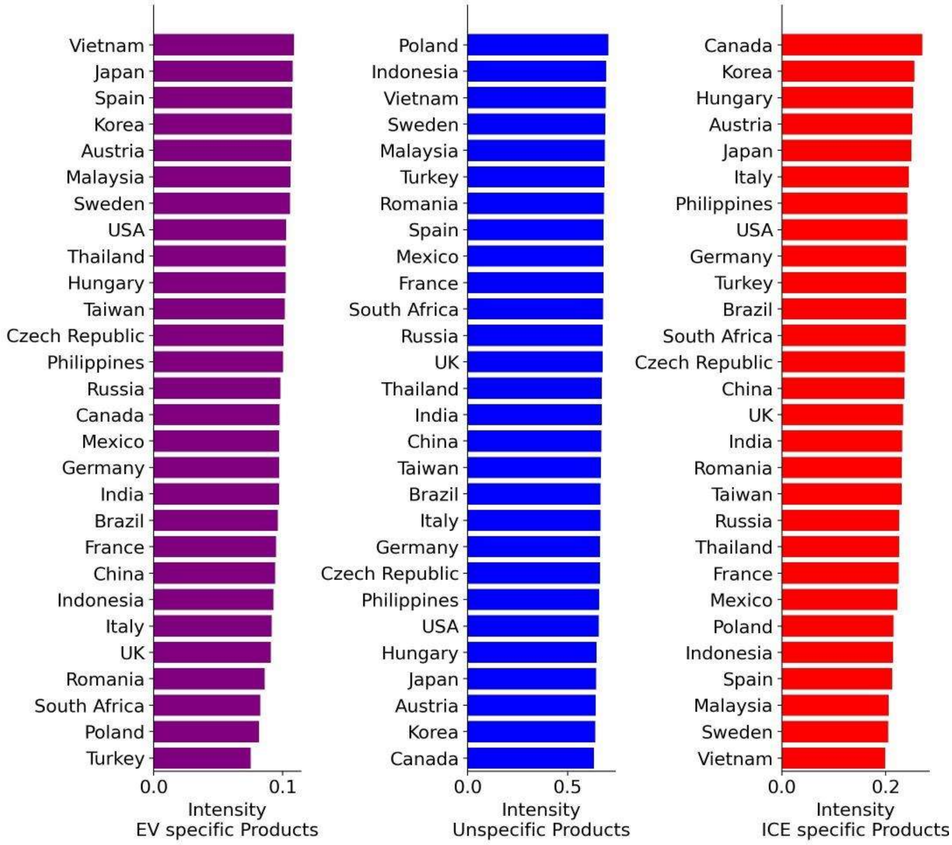

Figure 15: Intensity regarding EV specific, unspecific and ICE specific products per country for countries with 250 firms or more.

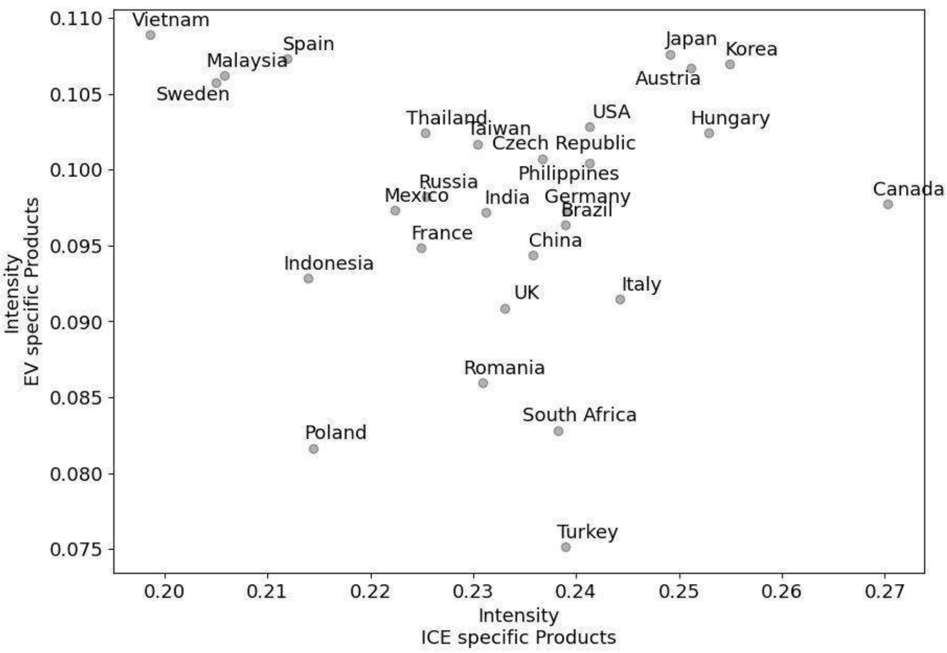

Figure 16: Relationship between Intensity of EV and ICE specific products for countries with 250 firms or more

To assess the significance of ICE /EV specific and unspecific products in each country, we compute the firm-share weighted proportion of the corresponding components for each country, referred to here as intensity. To compute the intensity of EV-specific products, we calculate for each EV-specific component

the share of firms in a region manufacturing this component and average this share over all EV-specific components. The intensities for ICE- and unspecific components are computed along similar lines by considering only ICE- and unspecific components, respectively.
This analysis reveals a slightly different picture when compared to the trade data, see Figure 16 and Figure 17. Vietnam, Japan, Spain, and Korea, for instance, show higher intensities of EV-specific components than China, suggesting that they have on average a higher proportion of companies producing such components than China, even though China leads in terms of export volume. Altogether, the intensity range is rather similar across countries.

These results suggest that many European countries generate most of their exports in monetary terms by ICE-specific components. However, the underlying company landscapes are stronger diversified in terms of EV-specific components than the highly aggregated exports would suggest. Austria ranks lower (has a higher intensity) in unspecific components compared to both ICE- and EV-specific components, suggesting a stronger diversification in these unspecific components. This mirrors industrial specialisation patterns.

3.4. From global to regional to local perspectives

The automotive industry is an important part of Upper Austria's manufacturing base. The concentration of automotive suppliers in Upper Austria is due to several factors. The region is home to a strong manufacturing tradition, with a skilled workforce and a well-developed infrastructure. Upper Austria is also located near major automotive production sites, such as the BMW plant in Steyr and the Magna plant in Graz.
Car suppliers are strongly concentrated in Upper Austria, which is challenged by the transition to EVs that exposes the region to substantial structural adjustment risks. The described methodical approach to develop (geopositioned and classified) stylized supply chain enables us to analyse companies supplying parts and components which are needed independently of the drive or specifically for ICEs or EVs.

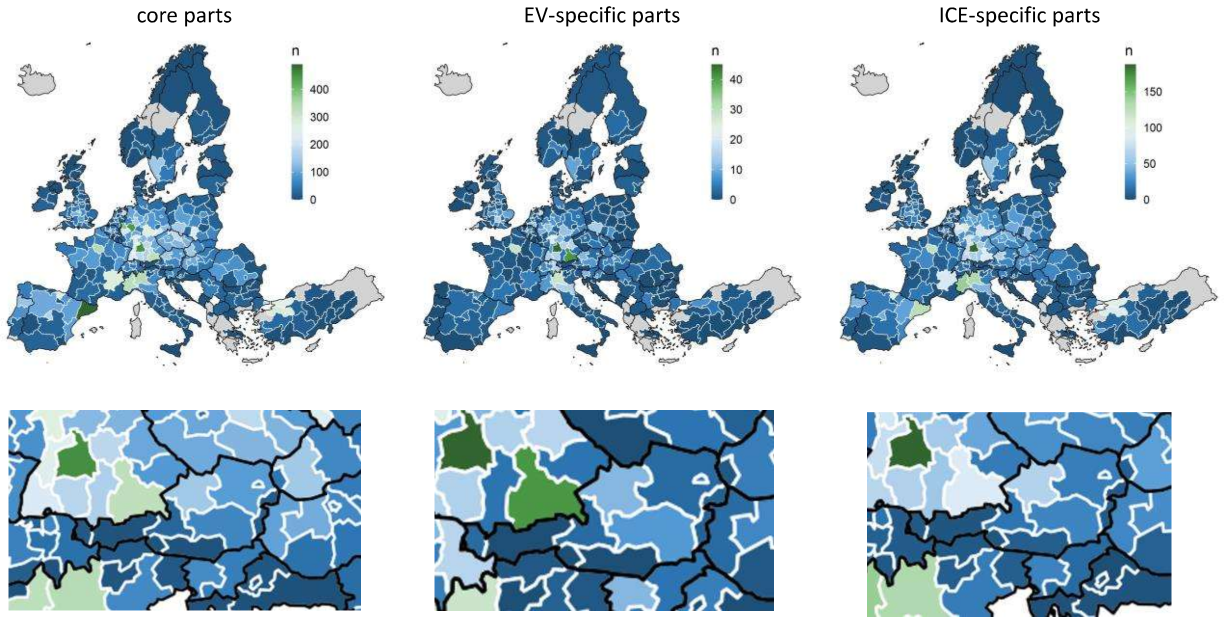

Figure 17: European companies in the automotive supply chain supplying unspecific parts, EV- and ICE-specific parts

Figure 17 shows the concentration of automotive suppliers in Upper Austria compared to other federal states. Hence, this indicator is a relative concentration measure. The transition from combustion engines to electric power units bears risks and opportunities for the supply base.

Figure 18: Austria's position in the EV supply chain

Figure 18 shows Austria's position compared to other European companies in product segments specific to EVs.

Currently, this analysis is based on our secondary-data analysis and needs to be validated with industry experts in a next step, to derive concrete next steps.
To further understand how characteristic specific products are for regions in Austria, we propose an indicator referred to as specificity ratio in the following. For a specific country or region, we calculate this specificity ratio relative to the global market by dividing the relative proportion of firms per product in a region and the relative proportion of firms per product in the entire dataset.
Results are shown in Figure 19. We find that Austria has its highest specificity ratio in unspecific modules (e.g., corner modules), followed by rotor and stator parts for drive motors (EV-specific components). Considering results specific for Upper Austria, we see that the latter two components are highly specific for this federal state, followed by another EV-specific component, namely battery cooling systems. The unspecific modules, however, are more specific for other regions in Austria. The analysis of firm-level data therefore reveals pronounced and specific strengths of Austrian companies in EV-specific components.

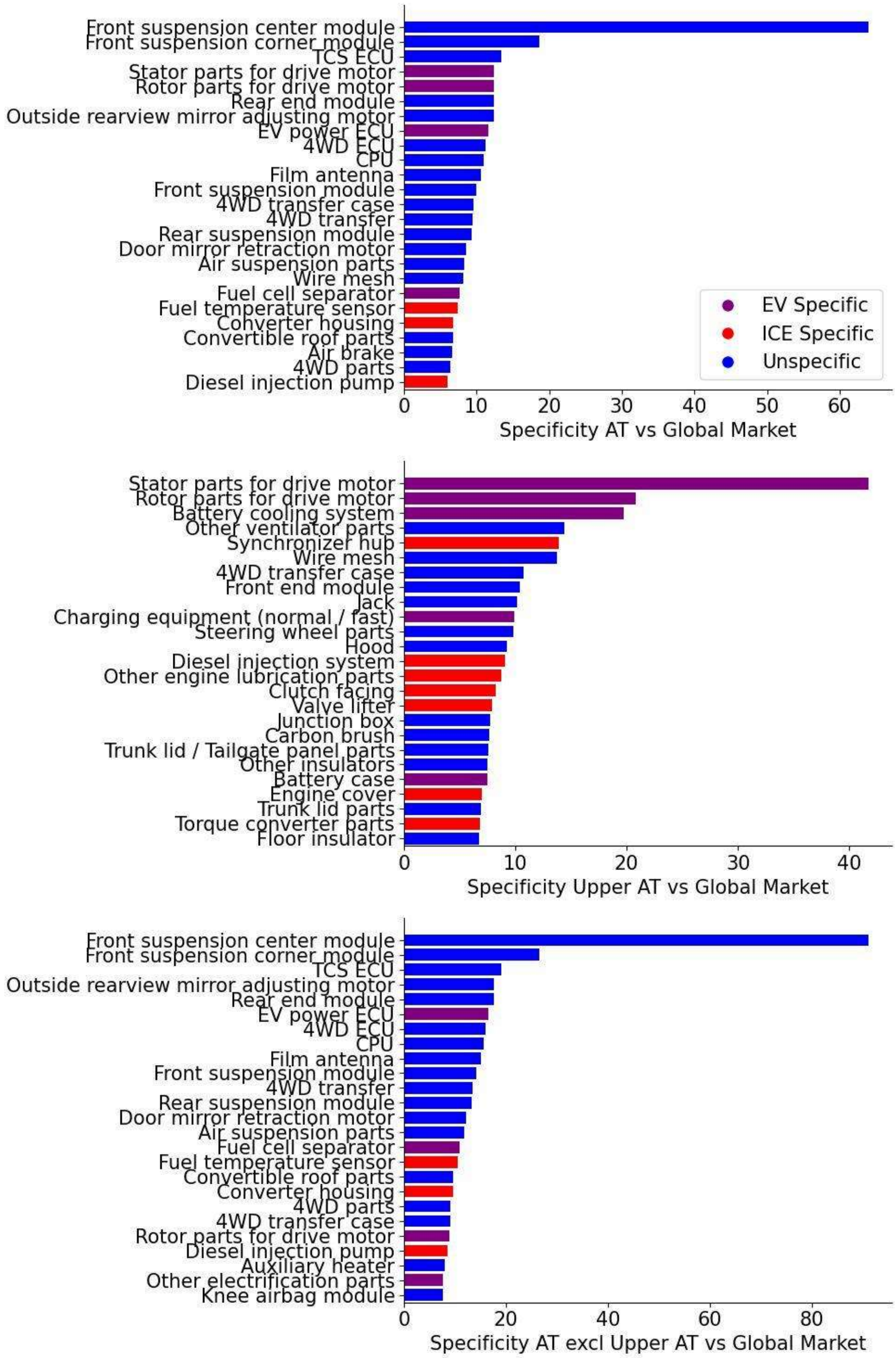

Figure 19: Specificity ratio for the 25 most specified products in Austria, Upper Austria and all other federal states compared to the global market.

4. Summary

The automotive industry, a sector of great economic relevance, is currently being challenged. The industry is currently undergoing a transition from conventional internal combustion engines to electric vehicles. This technical report lays some of the methodological groundwork for ASCII's future research of the industry's transition. It summarises first results of the transformation process. These include the international competitiveness of traded components, the potential for diversification and the regional distribution of production structures. This serves as a basis for an analysis of diversification potential to inform decision-makers. This analysis is based on a component approach (i.e. Harmonised System and Combined Nomenclature codes), which reflect production capacity at country level. It presents the status quo of the automotive industry's production structures using a component approach.

Comparing the export strength of different EV-specific products, China in particular has a comparative advantage in almost all EV-specific components, such as permanent magnets for AC and DC motors and EV climate control parts. China also has an export strength in EV-specific components where few other countries have a comparative advantage. Austria, although traditionally more focused on ICE-specific components, also has a strength in the production of a few EV-specific components such as electric axles, heat pump systems for electric climate control parts or winding wire for electrical purposes or types of DC and AC motors.

A product space analysis explores the diversification paths and suggests the underlying capabilities required to produce ICE or EV. The results suggest that there are fewer and more specific capability sets for EV-specific components than for ICE-specific components. The analysis clearly shows that there is no single transition path from ICE to EV. Rather, these paths are highly context dependent, depending on the current state of the regional economy and its embedded capabilities. This suggests that the transition is still a long way off and that innovation will be a major challenge for the car-producing regions concerned. This kind of structural change is a challenge for regional firm dynamics and thus industrial renewal. In Austria, these dynamics strongly depend on path dependency (Friesenbichler and Hölzl, 2020).

The results of the regional analysis are mixed. The data support the notion that Austrian and Upper Austrian companies have competitive advantages in internal combustion engines. They are lagging in the production of components for electric vehicles, which also reflects the capabilities at the company and regional level. However, it is important to note that the value chains are highly internationalised and that some key producers of critical parts for electric vehicles are in Austria. Upper Austria is not only exposed to transition risks, but also has potential in the production of key components for electric vehicles. These findings can be linked to regional industrial and innovation policies, such as the Future Mobility Region Upper Austria.

4.1. Next steps

The findings will be refined and further verified by additional industry experts, so that they may serve as a basis for subsequent transformation studies. Future topics may include the following topics:

- A first step is to quantify the economic relevance (i.e., to enrich the bill of materials will with volumes or proxy variables such as employment or value added of its producers) to assess the impact of the transition on firms and regions. This may include the impact on the labour market or productivity in the EU, Austria, or in current regional strongholds of the industry such as Upper Austria. This also relates to the development of regional capabilities strengthening the local capability base.
- The firm network effect also affects the parts of the car industry that is not directly affected by the transition in the powertrains. For instance, it is unclear if the producers of unspecific components that are potentially suppliers in both networks effectively supply both types of networks (e.g. producers supplying German OEMs as opposed to Chinese OEMs). Hence, further research includes mapping the ownership and control structures, or the role of ancillary industries.
- Electric vehicles rely on battery technology, which is resource intensive. As electric vehicles become more widespread, global demand for raw materials is likely to increase. This is likely to lead to global shortages with related price reactions, which will also affect production networks in the EU. This raises the question of how to introduce more circularity into EU supply chains and embed the industry in a wider circular economy.

The mapping of potential transition paths has so far considered only components within the automotive industry. Future research could address to which extent transition paths from ICE-specific components to other industries and from other industries to EV-specific components can be identified and which of these paths could be accessible to (Upper) Austrian companies.

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Appendix

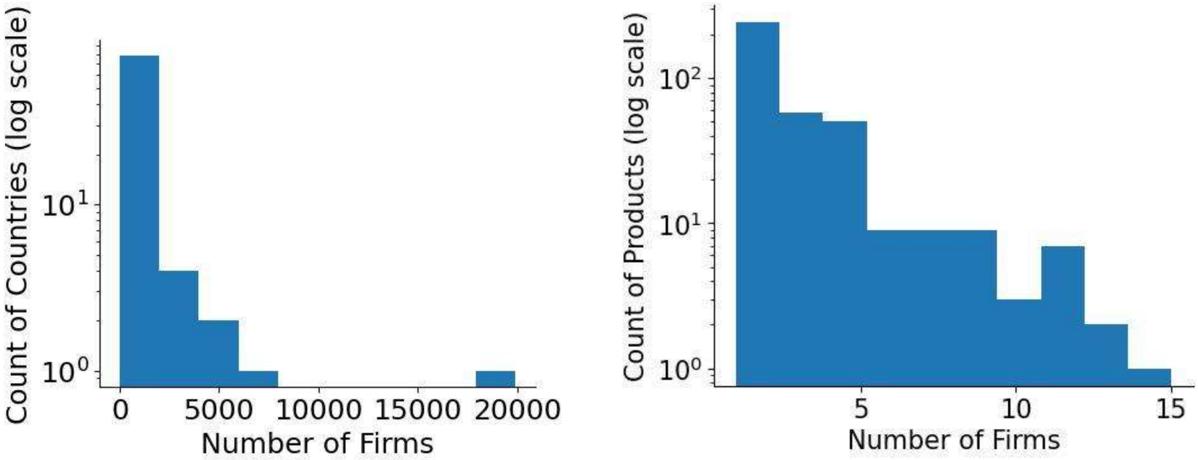


Figure A1: Distribution of number of products per firm in Austria and distribution of number of firms per product in Austria.

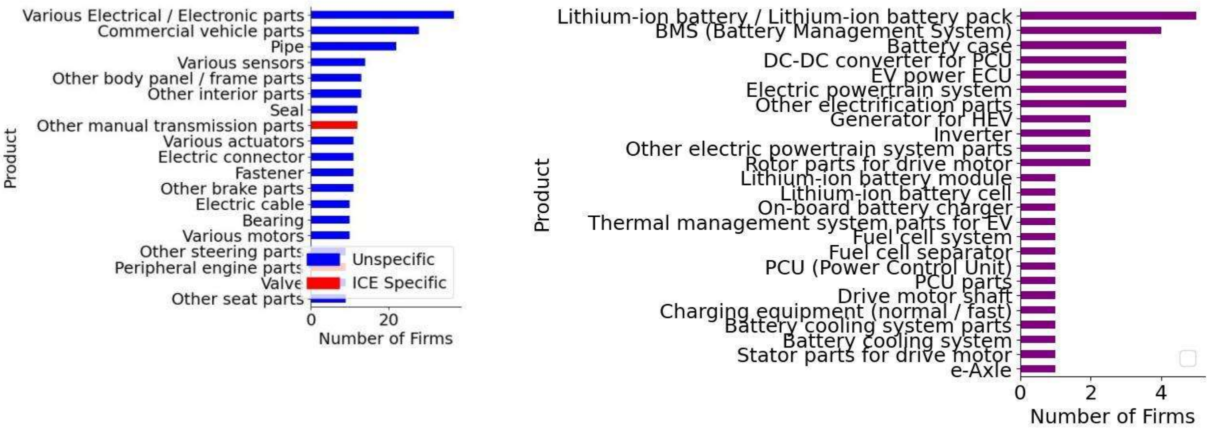
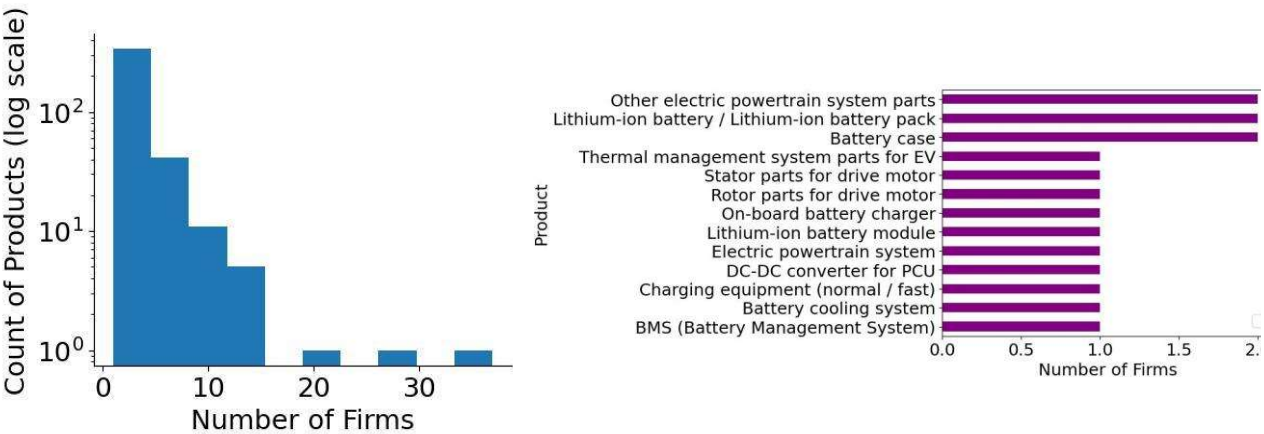


Figure A2: Number of firms per product in Austria for products which are produced by more than eight firms and number of firms per product in Austria for EV specific products.



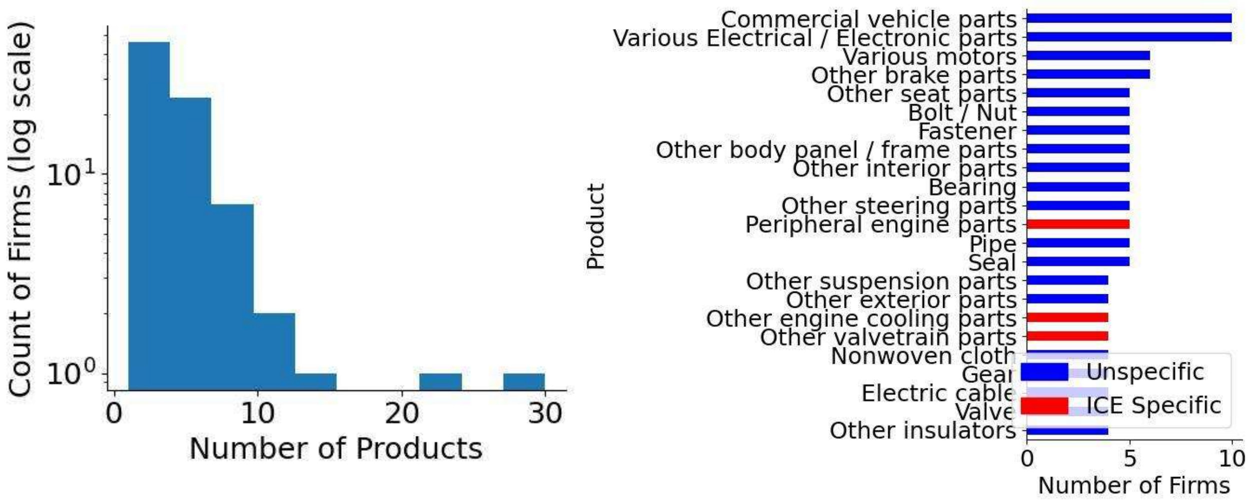


Figure A3: Distribution of number of products per firm in Upper Austria and distribution of number of firms per EV specific product in Upper Austria.

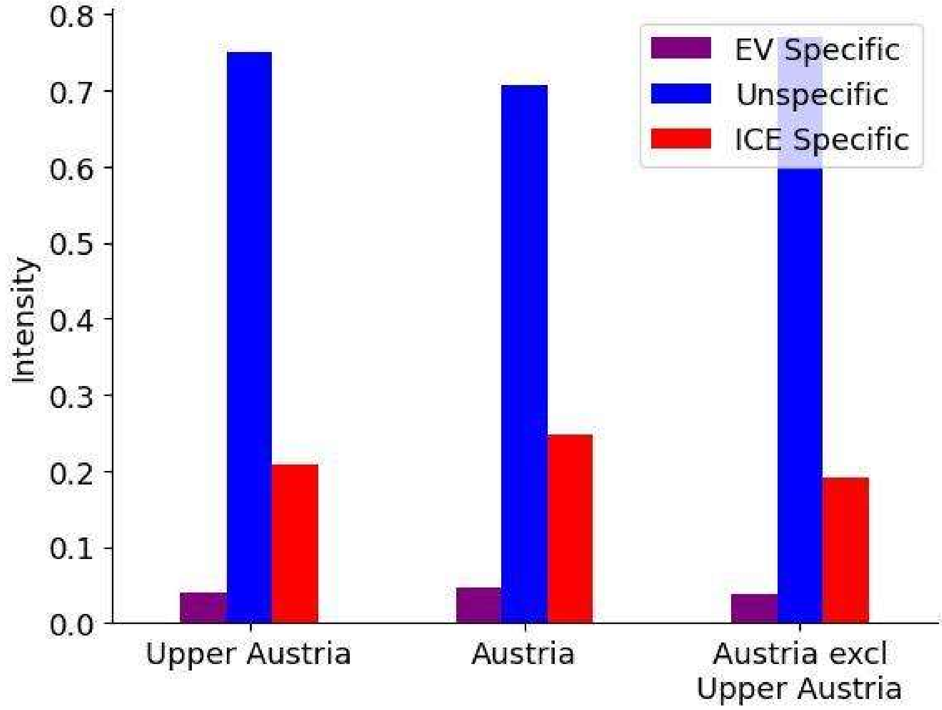


Figure A4: Intensity regarding EV specific, unspecific and ICE specific countries in Upper Austria, Austria, and all other federal states in Austria.

Table 1: List of EV-specific products on HS 6-digit level

HS6	Description
392630	Plastics; fittings for furniture, coachwork or the like
400912	Rubber; vulcanised (other than hard rubber), tubing, piping and hoses, not reinforced or otherwise combined with other materials, with fittings
400922	Rubber; vulcanised (other than hard rubber), tubing, piping and hoses, reinforced or otherwise combined only with metal, with fittings
850110	Electric motors; of an output not exceeding 37.5W
850120	Electric motors; universal AC/DC of an output exceeding 37.5W
850131	Electric motors and generators; DC, of an output not exceeding 750W
850132	Electric motors and generators; DC, of an output exceeding 750W but not exceeding 75kW
850133	Electric motors and generators; DC, of an output exceeding 75kW but not exceeding 375kW
850134	Electric motors and generators; DC, of an output exceeding 375kW
850140	Electric motors; AC motors, single-phase
850151	Electric motors; AC motors, multi-phase, of an output not exceeding 750W
850152	Electric motors; AC motors, multi-phase, of an output exceeding 750W but not exceeding 75kW
850153	Electric motors; AC motors, multi-phase, of an output exceeding 75kW
850161	Generators; AC generators, (alternators), of an output not exceeding 75kVA
850162	Electric generators; AC generators, (alternators), of an output exceeding 75kVA but not exceeding 375kVA
850163	Electric generators; AC generators, (alternators), of an output exceeding 375kVA but not exceeding 750kVA
850164	Electric generators; AC generators, (alternators), of an output exceeding 750kVA
850231	Electric generating sets; wind-powered, (excluding those with spark-ignition or compression-ignition internal combustion piston engines)
850239	Electric generating sets; (excluding those with spark-ignition or compression-ignition internal combustion piston engines), other than wind powered
850240	Electric rotary converters
850300	Electric motors and generators; parts suitable for use solely or principally with the machines of heading no. 8501 or 8502
850440	Electrical static converters
850450	Electrical inductors; n.e.c. in heading no. 8504
850490	Electrical transformers, static converters and inductors; parts thereof
850511	Magnets; permanent magnets and articles intended to become permanent magnets after magnetisation, of metal
850519	Magnets; permanent magnets and articles intended to become permanent magnets after magnetisation, other than of metal
850590	Magnets; electro-magnets, holding devices and parts n.e.c. in heading no. 8505
850610	Cells and batteries; primary, manganese dioxide
850630	Cells and batteries; primary, mercuric oxide
850640	Cells and batteries; primary, silver oxide
850650	Cells and batteries; primary, lithium
850660	Cells and batteries; primary, air-zinc
850680	Cells and batteries; primary, (other than manganese dioxide, mercuric oxide, silver oxide, lithium or air-zinc)
850690	Cells and batteries; primary, parts thereof
850720	Electric accumulators; lead-acid, (other than for starting piston engines), including separators, whether or not rectangular (including square)
850730	Electric accumulators; nickel-cadmium, including separators, whether or not rectangular (including square)
850750	Electric accumulators; nickel-metal hydride, including separators, whether or not rectangular (including square)
850760	Electric accumulators; lithium-ion, including separators, whether or not rectangular (including square)
850780	Electric accumulators; other than lead-acid, nickel-cadmium, nickel-iron, nickel-metal hydride and lithium-ion, including separators, whether or not rectangular (including square)
850790	Electric accumulators; parts n.e.c. in heading no. 8507

851629	Heating apparatus; electric soil heating apparatus and space heating apparatus (excluding storage heating radiators)
853510	Electrical apparatus; fuses, for a voltage exceeding 1000 volts
853521	Electrical apparatus; automatic circuit breakers, for a voltage exceeding 1000 volts but less than 72.5kV
853529	Electrical apparatus; automatic circuit breakers, for a voltage of 72.5kV or more
853530	Electrical apparatus; isolating and make-and-break switches, for a voltage exceeding 1000 volts
853540	Electrical apparatus; lightning arresters, voltage limiters and surge suppressors (for a voltage exceeding 1000 volts)
853590	Electrical apparatus; n.e.c. in heading no. 8535, for switching or protecting electrical circuits, for a voltage exceeding 1000 volts
853630	Electrical apparatus; for protecting electrical circuits, n.e.c. in heading no. 8536, for a voltage not exceeding 1000 volts
853641	Electrical apparatus; relays, (for a voltage not exceeding 60 volts)
853650	Electrical apparatus; switches n.e.c. in heading no. 8536, for a voltage not exceeding 1000 volts
853661	Electrical apparatus; lamp-holders, for a voltage not exceeding 1000 volts
853669	Electrical apparatus; plugs and sockets, for a voltage not exceeding 1000 volts
853670	Connectors for optical fibres, optical fibre bundles or cables
853690	Electrical apparatus; n.e.c. in heading no. 8536, for switching or protecting electrical circuits, for a voltage not exceeding 1000 volts
853710	Boards, panels, consoles, desks and other bases; for electric control or the distribution of electricity, (other than switching apparatus of heading no. 8517), for a voltage not exceeding 1000 volts
854110	Electrical apparatus; diodes, other than photosensitive or light-emitting diodes (LED)
854231	Electronic integrated circuits; processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits
854411	Insulated electric conductors; winding wire, of copper
854419	Insulated electric conductors; winding wire, (of other than copper)
854420	Insulated electric conductors; co-axial cable and other co-axial electric conductors
854442	Insulated electric conductors; for a voltage not exceeding 1000 volts, fitted with connectors
854449	Insulated electric conductors; for a voltage not exceeding 1000 volts, not fitted with connectors
854460	Insulated electric conductors; for a voltage exceeding 1000 volts
854470	Insulated electric conductors; optical fibre cables
870240	Vehicles; public transport type (carries 10 or more persons, including driver), with only electric motor for propulsion, new or used
870380	Vehicles; with only electric motor for propulsion

Table 2: List of ICE-specific products on HS 6-digit level

HS6	Description
382000	Anti-freezing preparations and prepared de-icing fluids
731511	Chain; articulated link, roller, of iron or steel
840731	Engines; reciprocating piston engines, of a kind used for the propulsion of vehicles of chapter 87, of a cylinder capacity not exceeding 50cc
840732	Engines; reciprocating piston engines, of a kind used for the propulsion of vehicles of chapter 87, of a cylinder capacity exceeding 50cc but not exceeding 250cc
840733	Engines; reciprocating piston engines, of a kind used for the propulsion of vehicles of chapter 87, of a cylinder capacity exceeding 250cc but not exceeding 1000cc
840734	Engines; reciprocating piston engines, of a kind used for the propulsion of vehicles of chapter 87, of a cylinder capacity exceeding 1000cc
840790	Engines; rotary internal combustion piston engines, for other than aircraft or marine propulsion
840820	Engines; compression-ignition internal combustion piston engines (diesel or semi-diesel engines), of a kind used for the propulsion of vehicles of chapter 87
840890	Engines; compression-ignition internal combustion piston engines (diesel or semi-diesel engines), of a kind used for other than marine propulsion or the vehicles of chapter 87
840991	Engines; parts, suitable for use solely or principally with spark-ignition internal combustion piston engines (for other than aircraft)
840999	Engines; parts for internal combustion piston engines (excluding spark-ignition)
841221	Engines; hydraulic power engines and motors, linear acting (cylinders)
841231	Engines; pneumatic power engines and motors, linear acting (cylinders)
841239	Engines; pneumatic power engines and motors, other than linear acting (cylinders)
841330	Pumps; fuel, lubricating or cooling medium pumps for internal combustion piston engines
841459	Fans; n.e.c. in item no. 8414.51
842123	Machinery; filtering or purifying machinery, oil or petrol filters for internal combustion engines
848360	Clutches and shaft couplings (including universal joints)
851110	Ignition or starting equipment; spark plugs, of a kind used for spark or compression-ignition internal combustion engines
851120	Ignition or starting equipment; ignition magnetos, magneto-dynamos and magnetic flywheels, of a kind used for spark or compression-ignition internal combustion engines
851130	Ignition or starting equipment; distributors and ignition coils of a kind used for spark-ignition or compression-ignition internal combustion engines
851140	Ignition or starting equipment; starter motors and dual purpose starter-generators, of a kind used for spark or compression-ignition internal combustion engines
851150	Ignition or starting equipment; generators n.e.c. in heading no. 8511, of a kind used for spark or compression-ignition internal combustion engines
851180	Ignition or starting equipment; n.e.c. in heading no. 8511, of a kind used for spark or compression-ignition internal combustion engines
851190	Ignition or starting equipment; parts of the equipment of heading no. 8511, for use in spark-ignition or compression-ignition internal combustion engines
870110	Tractors; single axle
870210	Vehicles; public transport type (carries 10 or more persons, including driver), with only compression-ignition internal combustion piston engine (diesel or semi-diesel), new or used
870290	Vehicles; public transport type (carries 10 or more persons, including driver), n.e.c. in heading 8702, new or used
870600	Chassis; fitted with engines, for the motor vehicles of heading no. 8701 to 8705
870840	Vehicle parts; gear boxes and parts thereof
870891	Vehicle parts; radiators and parts thereof
870892	Vehicle parts; silencers (mufflers) and exhaust pipes; parts thereof
870893	Vehicle parts; clutches and parts thereof

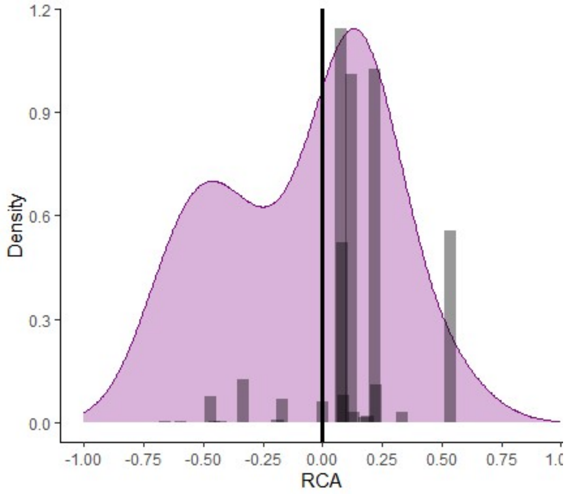
Table 3: List of unspecified products on HS 6-digit level

HS6	Description
392690	Plastics; other articles n.e.c. in chapter 39
401032	Rubber; vulcanised, endless transmission belts of trapezoidal cross-section (V-belts), other than V-ribbed, of an outside circumference exceeding 60cm but not exceeding 180 cm
401035	Rubber; vulcanised, endless synchronous belts, of an outside circumference exceeding 60 cm but not exceeding 150 cm
401110	Rubber; new pneumatic tyres, of a kind used on motor cars (including station wagons and racing cars)
401120	Rubber; new pneumatic tyres, of a kind used on buses or lorries
401140	Rubber; new pneumatic tyres, of a kind used on motorcycles
401691	Rubber; vulcanised (other than hard rubber), floor coverings and mats, of non-cellular rubber
401693	Rubber; vulcanised (other than hard rubber), gaskets, washers and other seals, of non-cellular rubber
401699	Rubber; vulcanised (other than hard rubber), articles n.e.c. in heading no. 4016, of non-cellular rubber
570242	Carpets and other textile floor coverings; woven, (not tufted or flocked), of man-made textile materials, of pile construction, made up, n.e.c. in item no. 5702.10 or 5702.20
681389	Friction material and articles thereof (e.g. sheets, rolls, strips, segments, discs, washers, pads) not mounted; for clutches or the like (not brake linings and pads), with a basis of mineral substances or cellulose (other than asbestos)
700711	Glass; safety glass, toughened (tempered), of size and shape suitable for incorporation in vehicles, aircraft, spacecraft or vessels
700910	Glass; rear-view mirrors for vehicles
701400	Glassware; signalling, (not optically worked)
730723	Steel, stainless; tube or pipe fittings, butt welding fittings
731210	Iron or steel; stranded wire, ropes and cables, not electrically insulated
731815	Iron or steel; threaded screws and bolts n.e.c. in item no. 7318.1, whether or not with their nuts or washers
731816	Iron or steel; threaded nuts
731822	Iron or steel; non-threaded washers, excluding spring and lock
731823	Iron or steel; non-threaded rivets
731824	Iron or steel; non-threaded cotters and cotter-pins
731829	Iron or steel; non-threaded articles, n.e.c. in item no. 7318.2
732020	Iron or steel; helical springs and leaves for springs
732620	Iron or steel; wire articles
830120	Locks; of a kind used for motor vehicles (key, combination or electrically operated), of base metal
830230	Mountings, fittings and similar articles; for motor vehicles, of base metal
830710	Tubing; flexible, with or without fittings, of iron or steel
830820	Rivets; tubular or bifurcated, of base metal
841410	Pumps; vacuum
841480	Pumps and compressors; for air, vacuum or gas, n.e.c. in heading no. 8414
841520	Air conditioning machines; comprising a motor driven fan and elements for changing the temperature and humidity, of a kind used for persons, in motor vehicles
848130	Valves; check (nonreturn) valves, for pipes, boiler shells, tanks, vats or the like
848240	Bearings; needle roller bearings
848310	Transmission shafts (including cam shafts and crank shafts) and cranks
848320	Bearing housings, incorporating ball or roller bearings
848330	Bearing housings, not incorporating ball or roller bearings and plain shaft bearings
848340	Gears and gearing; (not toothed wheels, chain sprockets and other transmission elements presented separately); ball or roller screws; gear boxes and other speed changers, including torque converters
848350	Pulleys and flywheels, including pulley blocks
848390	Transmission components; toothed wheels, chain sprockets and other transmission elements presented separately; parts
850211	Electric generating sets; with compression-ignition internal combustion piston engines (diesel or semi-diesel engines), of an output not exceeding 75kVA

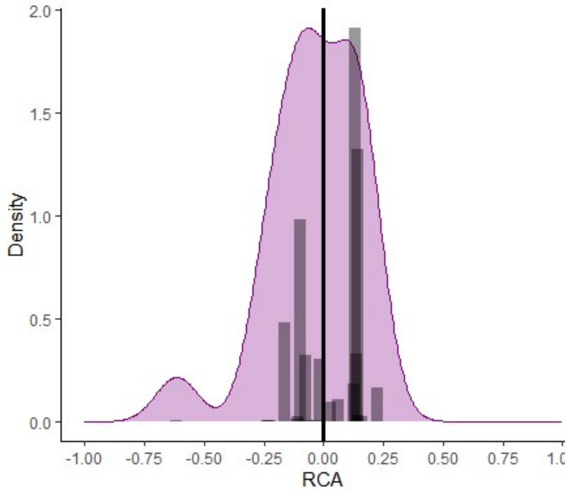
850212	Electric generating sets; with compression-ignition internal combustion piston engines (diesel or semi-diesel engines), of an output exceeding 75kVA but not exceeding 375kVA
850213	Electric generating sets; with compression-ignition internal combustion piston engines (diesel or semi-diesel engines), of an output exceeding 375kVA
850220	Electric generating sets; with spark-ignition internal combustion piston engines
850520	Magnets; electro-magnetic couplings, clutches and brakes
850710	Electric accumulators; lead-acid, of a kind used for starting piston engines, including separators, whether or not rectangular (including square)
851220	Lighting or visual signalling equipment; electrical, of a kind used on motor vehicles (excluding articles of heading no. 8539)
851230	Sound signalling equipment; electrical, used on cycles or motor vehicles (excluding articles of heading no. 8539)
851240	Windscreen wipers, defrosters and demisters; electrical, of kinds used for cycles or motor vehicles
851290	Lighting or signalling equipment; electrical, (excluding articles of heading no. 8539), windscreen wipers, defrosters and demisters; parts, of those kinds used for cycles or motor vehicles
852729	Radio-broadcast receivers not capable of operating without an external source of power, of a kind used in motor vehicles; not combined with sound recording or reproducing apparatus
852910	Reception and transmission apparatus; aerials and aerial reflectors of all kinds and parts suitable for use therewith
853222	Electrical capacitors; fixed, aluminium electrolytic
853321	Electrical resistors; fixed, for a power handling capacity not exceeding 20W (including rheostats and potentiometers but excluding heating resistors and carbon resistors)
853400	Circuits; printed
853610	Electrical apparatus; fuses, for a voltage not exceeding 1000 volts
853620	Electrical apparatus; automatic circuit breakers, for a voltage not exceeding 1000 volts
853649	Electrical apparatus; relays, for a voltage exceeding 60 volts
853921	Lamps; filament, (excluding ultra-violet or infra-red), tungsten halogen
853929	Lamps; filament, (excluding ultra-violet or infra-red), n.e.c. in item no. 8539.2
853932	Lamps; discharge, (excluding ultra-violet), mercury or sodium vapour lamps, metal halide lamps
854430	Insulated electric conductors; ignition wiring sets and other wiring sets of a kind used in vehicles, aircraft or ships
870710	Vehicles; bodies (including cabs) for the motor vehicles of heading no. 8703
870790	Vehicles; bodies (including cabs) for the motor vehicles of heading no. 8701, 8702, 8704 or 8705
870810	Vehicles; bumpers and parts thereof, for the vehicles of heading no. 8701 to 8705
870821	Vehicles; parts of bodies, safety seat belts
870829	Vehicles; parts and accessories, of bodies, other than safety seat belts
870830	Vehicle parts; brakes, servo-brakes and parts thereof
870870	Vehicle parts; road wheels and parts and accessories thereof
870880	Vehicle parts; suspension systems and parts thereof (including shock-absorbers)
870894	Vehicle parts; steering wheels, steering columns and steering boxes; parts thereof
870895	Vehicle parts; safety airbags with inflater system; parts thereof
870899	Vehicle parts and accessories; n.e.c. in heading no. 8708
902910	Meters and counters; revolution counters, production counters, taximeters, mileometers, pedometers and the like
903210	Regulating or controlling instruments and apparatus; automatic type, thermostats
940120	Seats; of a kind used for motor vehicles

Scenario - Automotive only

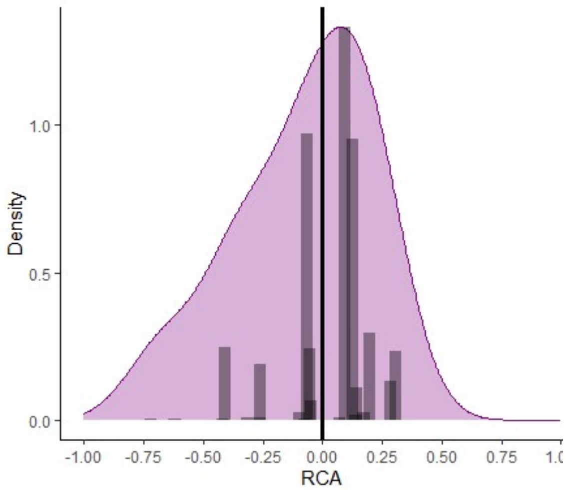
Histograms/Density plots (EV)



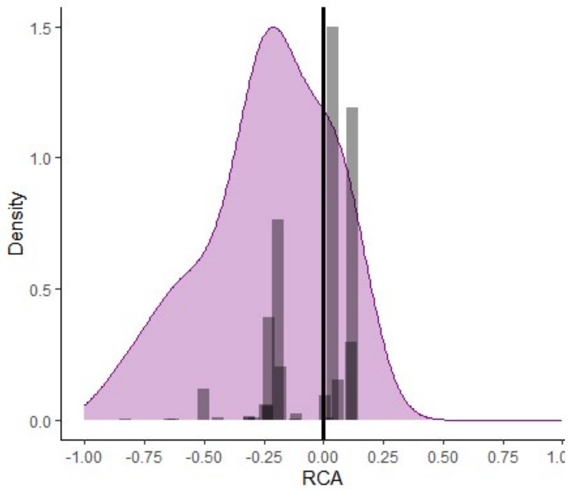
(a) Austria



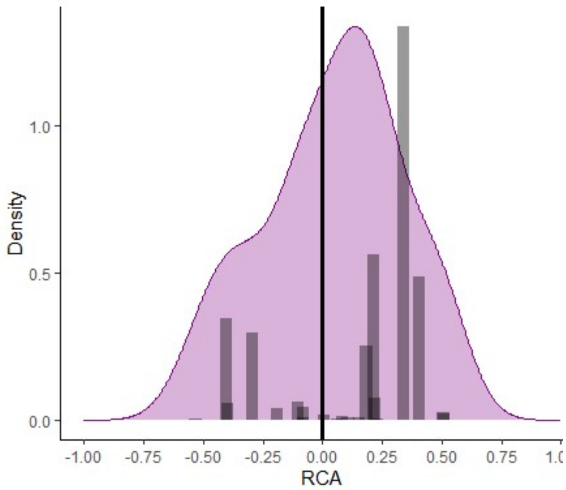
(b) EU (incl. intra-EU trade)



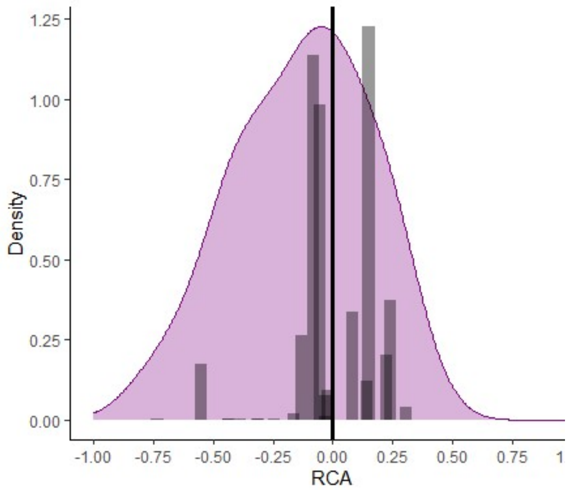
(c) EU (excl. intra-EU trade)



(d) USA



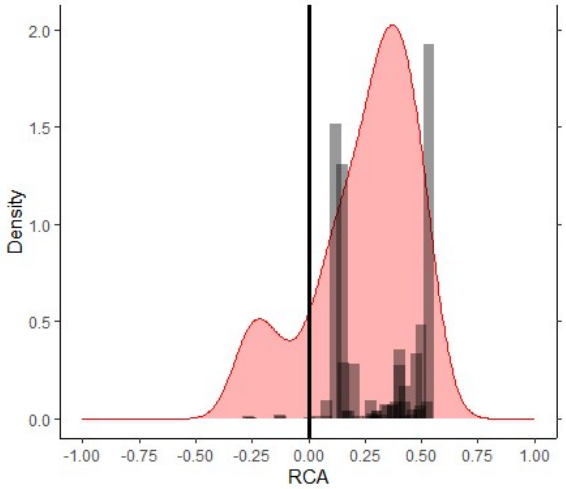
(e) China



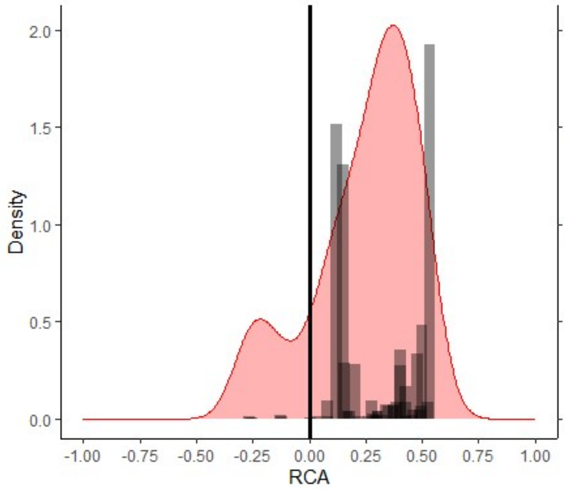
(f) Germany

Figure A5: Revealed comparative advantages over EV-specific products in 2021

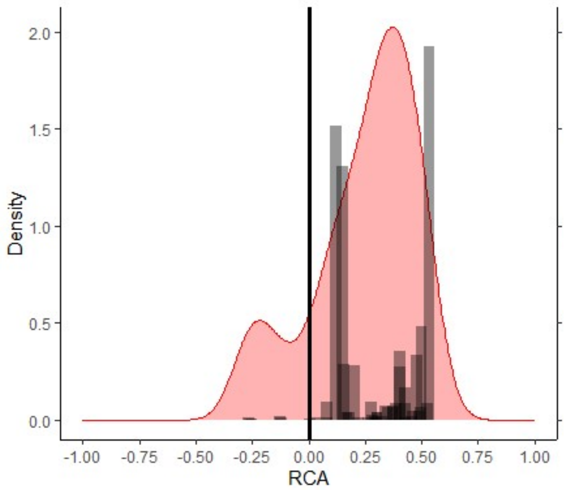
Histograms/Density plots (ICE)



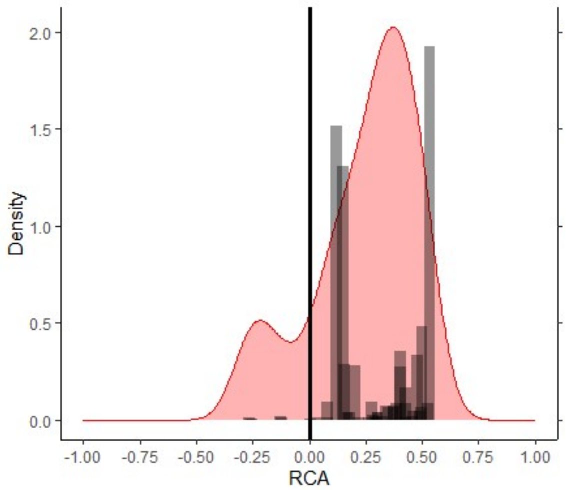
(a) Austria



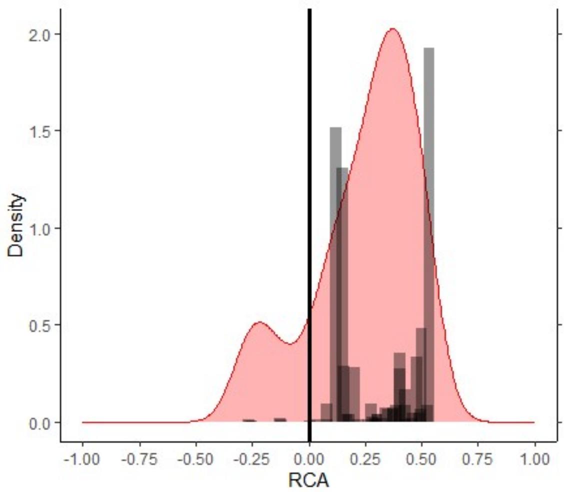
(b) EU (incl. intra-EU trade)



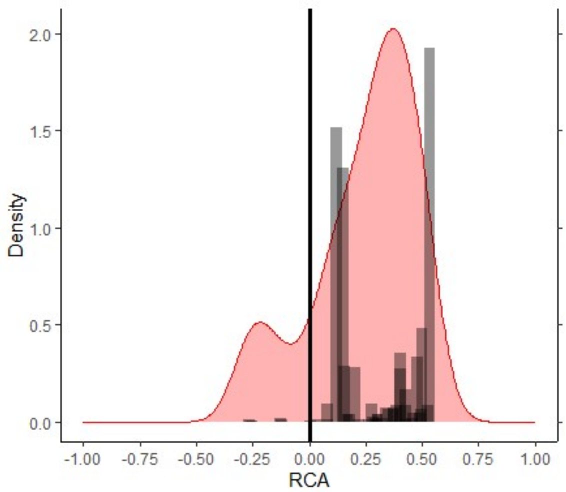
(c) EU (excl. intra-EU trade)



(d) USA



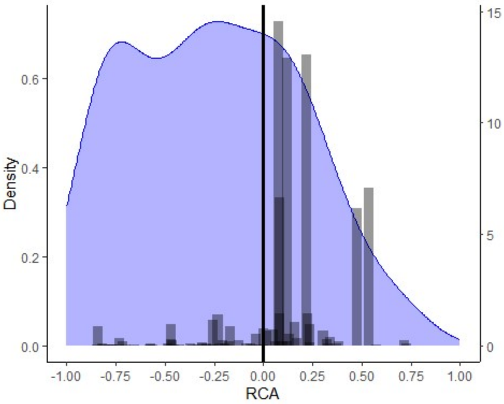
(e) China



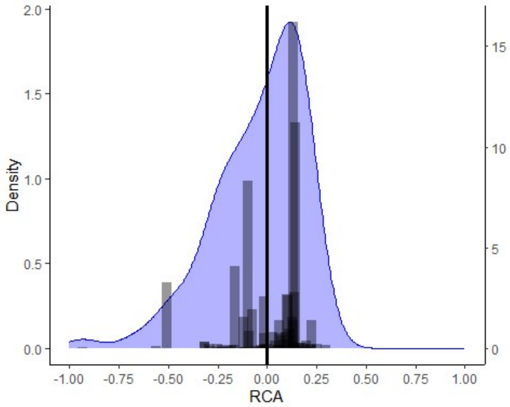
(f) Germany

Figure A6: Revealed comparative advantages over ICE-specific products in 2021

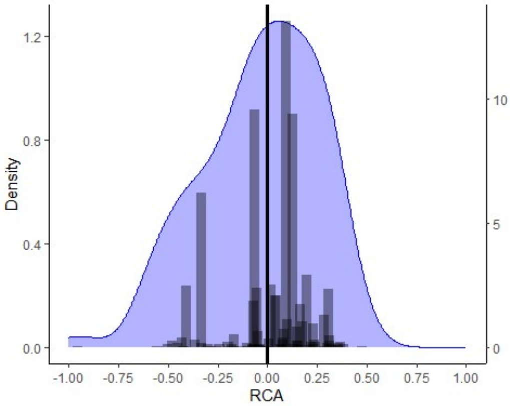
Histograms/Density plots (EV & ICE are regarded unspecified)



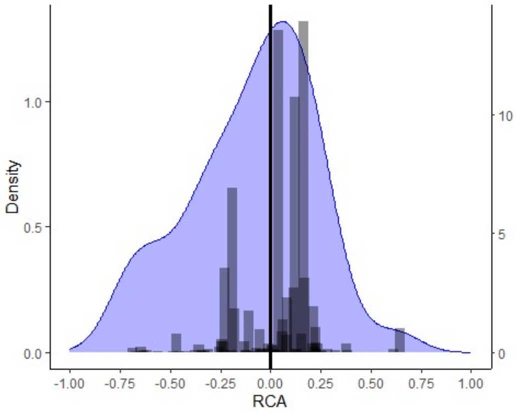
(a) Austria



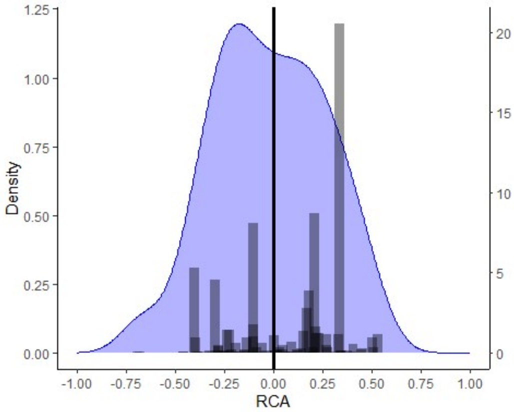
(b) EU (incl. intra-EU trade)



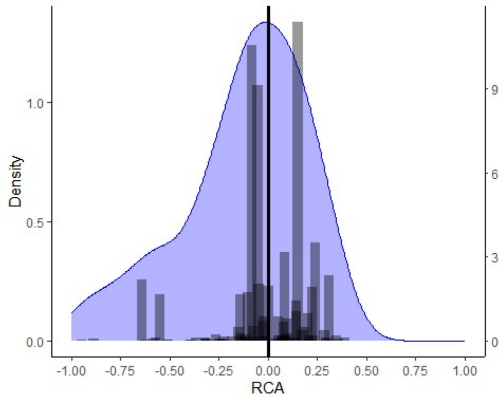
(c) EU (excl. intra-EU trade)



(d) USA



(e) China



(f) Germany

Figure A7: Revealed comparative advantages over unspecific products in 2021