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## Abstract

Analysing the automobile sector is important for understanding the evolution of many economies in the EU. This is because of the sector's direct importance in terms of GDP and employment, its sensitivity to the economic cycle, as well as its extended role in the economy through supply chains. While our analysis covers all EU Member States, we focus particularly on France and Germany. The aim of this study is to evaluate recent trends in the automobile and related sectors using a global value chain (GVC) approach. Building on these results, we evaluate the potential impact across countries and sectors of a hypothetical negative demand shock for cars. We conclude the analysis by studying the current position of the automobile sector across countries in light of the transition towards electric vehicles.

Our main finding confirms that carmakers in France and Germany have chosen different production strategies. While French carmakers have traditionally relied much more on offshoring final production, German car makers seems to have retained much more assembly at home, while offshoring intermediates to neighbouring countries. Moreover, we find that a hypothetical shock of 10% to the final demand for cars by EU consumers could lead to a 0.2% drop in total employment demand in France, placing it at the European average. Germany, however, would suffer from a greater loss of 0.7% in total employment demand. In view of the upcoming shift towards electric car technologies and autonomous driving, we find evidence suggesting that countries in the EU are lagging behind China and the US when it comes to the production of electric parts used in the car sector.

**JEL Classification:** C67, D57, F14, F17, L62.

**Keywords**: Supply Chains, Automobiles, Sector Analysis, Leontief, Input-Output.

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# 1. INTRODUCTION

Analysing the automobile sector is important for understanding the evolution of many economies in the EU.[1] This is because of the sector's direct importance in terms of GDP and employment, its sensitivity to the economic cycle, as well as its extended role in the economy through national and international value chains. While our analysis covers all EU Member States, we focus particularly on France and Germany, as these countries are widely seen as two opposite paradigms in the way the automobile industry has evolved over the past few decades. Studying the transformation of the automobile industry is a complex exercise given the extensive international fragmentation of production that has taken place in recent decades (Sturgeon et al., 2008). For this reason, our analysis takes a global value chain (GVC) approach in order to evaluate recent trends in the automobile industry and related sectors. Building on these results, we are able to evaluate the potential impact across countries and sectors of a hypothetical negative demand shock for cars. We complement the analysis by describing the current position of countries in light of the ongoing shift towards electric vehicles.

The global fragmentation of car production has been motivated by innovations within the industry, primarily aimed at reducing costs (such as "lean production systems"[2]), as well as changes in the global economic environment. In Europe in particular, several changes in the economic environment have contributed to a significant reshaping of sourcing patterns. The enlargement of the EU enabled multinational companies to benefit from lower labour costs, first in Southern countries (Spain and Portugal) and then in Central and Eastern European countries (Hungary, Slovakia, Slovenia, Romania, and Poland), using the new plants as export platforms. The integration of production in these countries followed a gradual process. Initially, new assembly plants were mainly supplied from the existing bases. After the development of local sectors, sourcing patterns adjusted to incorporate the most efficient emerging suppliers (Bilbao-Ubillos and Camino Beldarrain, 2008), contributing positively to the geographical fragmentation of car manufacturing. Another economic factor contributing to the fragmentation of the European car industry was the establishment of local assembly plants by Asian firms, and the wave of mergers and acquisitions by the largest carmakers and suppliers (Schmitt et al., 2013).

While the previous decades have seen important changes, car producers still face several challenges that affect both the demand and the supply side of their operations. On the demand side, global car sales have been decreasing since 2018. These developments have occurred worldwide: in 2018, car sales decreased by 1.7% in the EU, compared to 1.3% in North America and 2.5% in China. Some automobile sector experts argue that global demand for cars may have already peaked and may decline over the coming years.[3] Several factors could explain this evolution. First, a growing urban population is likely to negatively affect the final demand for cars, given the negative correlation between per capita car kilometres or car ownership and urban density (Kenworthy and Laube (1999)). Moreover,

[1] Given that we are using data from 2016, we will refer to the EU as the EU-27 plus the UK throughout the analysis.

[2] Lean manufacturing is a methodology that focuses on minimising waste within manufacturing systems while simultaneously maximising productivity. The benefits of lean include reduced lead times, reduced operating costs and improved product quality.

[3] See https://edition.cnn.com/2020/01/20/business/global-auto-recession/index.html for more details.

young generations are less likely to use and own a private car than older generations. Finally, the uncertainty arising from foreseen technological changes and stringent regulations that aim to reduce overall pollution could further decrease the demand for cars. More recently, in the short term, the demand of automobiles has been particularly affected by the COVID-19 outbreak. This drop in demand may persist in the longer run as households decide to postpone non-essential purchases such as that of a new car. The negative demand-side effects may become further entrenched as a result of global losses in income and purchasing power.

On the supply side, an important structural change affecting the industry relates to the transition towards electric vehicles. For example, while 17,000 electric cars were on the world's roads in 2010, the number increased sharply to 7.2 million in 2019, of which 47% were in China and 24% in Europe. The market share of electric cars has reached more than 1% in at least in 20 countries and electric cars represented 2.6% of worldwide car sales and 3.5% of European car sales in 2019. Worldwide, 2.1 million electric cars were sold in 2019, up 6% compared to 2018.[4] In Europe, a number of national and EU policies concerning electric mobility help foster these changes and support EU producers. For example, in order to speed up developments on the market for electric mobility, major European car producing countries implemented infrastructure investment and financial incentives for alternative fuel transport (e.g. the German National Development Plan for Electric Mobility or French "Loi Energie-climat and Loi d'orientation des mobilités"). These plans are important given that while the electric car might have important benefits in terms of meeting environmental targets, the potential industry-wide shift might result in changes to the production process, with fewer parts required, and fewer workers needed in their assembly. For example, while most carmakers produce their own internal combustion engines, they rely on a handful of global suppliers for batteries, which are arguably produced through a largely automated process.[5] In the short term, factory shutdowns following the COVID-19 outbreak have severely affected automobile producers across the EU, resulting in large production losses that are likely to increase if shutdowns are extended. Supply chain disruptions have further underlined the vulnerability of EU car production processes to a smooth functioning of global and European value chains. The pandemic, and the reconstruction phase that follows it, provide opportunities to accelerate the above-described transition towards a greener automobile industry.

While our analysis can give an indication of the potential impact of the crisis caused by the COVID-19 pandemic, our primary focus lies on the implications of the structural changes described above. In order to understand potential future changes in the industry, it is important to understand what has happened in the last decade. Consequently, this analysis aims first to evaluate and decompose the recent evolution of the role of the automobile sector and related sectors in EU countries, with a particular focus on France and Germany. Building on these results, it evaluates the potential impact across countries and sectors of a hypothetical negative demand shock for cars by consumers around the world, decomposing the economic effect by geographical region. Finally, we analyse the readiness of EU economies to adapt to the upcoming transformation of the automotive industry towards electric vehicles. We identify the countries with a potential first-mover advantage in the transition by assessing their specialisation in sectors that produce electronic components for the car industry. It is important to

[4] See https://www.iea.org/reports/global-ev-outlook-2020 for more details.

[5] See https://www.nbcnews.com/business/autos/electric-vehicles-pose-real-risk-autoworkers-halving-number-people-required-n1060426 or https://edition.cnn.com/2019/12/04/business/electric-car-job-threat/index.html for specific examples as to how production of cars might change.

highlight that throughout our analysis all the sectoral production interlinkages across countries are taken into account.

Main findings:

We find that the importance of the car industry in the total economy[6] has decreased over the past decade in France and Belgium, and to a lesser extent in Sweden, Spain and Italy. On the other hand, the industry's relative importance has risen in Slovakia, Czechia, Romania, Bulgaria and Hungary. The car industry in Germany has roughly maintained its weight in the German economy over the period.

The factors driving these developments differ across countries. For France, the decline in the relative importance of the car industry seems to be have been driven mainly by the change in the global value chain production structure and, to a lesser extent, lower demand for cars using French inputs. Germany, on the other hand, seems to have benefitted from an increased demand for its cars over the past decade, but this positive effect has been mitigated by a lower use of domestic labour in the car production. Central and Eastern European countries seem to have benefitted mostly from an increased final demand for cars using their inputs and an increased participation in global value chains.

Thus, the change in the structure of automobile industry supply chains has been an important factor in shaping the European car industry in recent decades. While most countries that joined the European Union since 2004 have increased their participation in the global supply chains of cars and Germany has kept its position relatively stable, France has seen its participation decrease significantly in the last decade. This finding suggests that carmakers in France and Germany have chosen different production strategies. While French carmakers have relied much more on offshoring final production, Germany seems to have retained much more assembly at home, while offshoring intermediates to neighbouring countries. Maravall-Rodriguez and Küffel (2018) complement this finding with the observation that while the final production of cars has dropped in France, global production of French brands has not decreased in the last two decades.

Taking into account the international supply chains of the car industry, we evaluate the exposure of different EU countries to worldwide negative demand shocks in the car industry. Applying a hypothetical shock of 10% to the final demand for cars by EU consumers, for example, we find that France would experience a drop in national employment demand of 0.21%, which is about the EU average. The total change in employment includes both direct and indirect losses through other sectors used in the production process of cars. Germany would suffer from a greater loss of 0.73% of total employment. Both in France and Germany, a negative demand shock in the domestic and other EU markets affects employment demand in a similar manner, indicating the importance of the domestic market for both countries. On the other hand, we observe that Central and Eastern European countries such as Czechia, Slovakia and Hungary are more exposed to a demand shock by foreign EU rather than domestic consumers. This reflects the importance of the automotive sector in these countries and their strong participation in European value chains. We also evaluate the impact of a negative shock to the final demand for cars by non-EU consumers. In this case, we find that the most affected countries are Czechia, Slovakia, Hungary and Germany. France, on the other hand, is not particularly affected by a negative shock to demand for cars by non-EU consumers.

[6] Measured as a share of total employment.

As mentioned above, the growing significance of electric vehicles may have important economic implications, given the potential increase in the share of electronic components compared to the current car production process.[7] If this sectoral transformation materialises, some countries will gain economic activity whereas others will lose from the potential reduction in the use of their components in the production process of cars using combustion engines. In this analysis, we find evidence which suggests that the EU is lagging behind China and the US when it comes to the shift towards electric car technologies and autonomous driving. We argue that these countries have a first mover advantage given that they are the largest contributors of electronic components in the global supply chains of cars, followed by the EU at a long distance.

The remainder of this analysis is organised as follows. In section 2, we describe the methodology used in this analysis. Section 3 shows the importance of the car industry in each EU country, it estimates the evolution of the importance of the car industry in the last decade for each country-sector pair and ends with a simulation of the impact of a potential demand shock on each EU economy. Section 4 concludes.

# 2. METHODOLOGY

This section describes the methodology used in order to evaluate the past and potential future evolution of the importance of the automobile sector in the EU member states, with a particular focus on France and Germany. It is particularly useful as it takes into account the highly integrated global value chains in the car industry. This is highlighted by Arto et al. (2019) who argue that using conventional statistics that do not consider its interlinkages with other national and international sectors may give a distorted picture in a fragmented sector like the car industry.

Consistently with our theoretical foundations of the methodology developed in the Appendix of this paper, superscripts represent the origin and subscripts indicate the destination of flows of goods and services. For example, $X_{FR,car}^{FR,services}$ captures the intermediate use of French services as inputs by the French car industry. Final good flows are described in a similar manner, where $f_{PL}^{FR,cars}$ refers to the value of final demand of cars produced in France and consumed in Poland. Another important notation refers to country aggregates where, for example, gross output of French cars is expressed by $y^{FR,Cars}$. Throughout this paper, countries are denoted by *i*, *j* and *k* and sectors by *r*, *s* and *z.*

Using the condition that production should be consumed either in the form of intermediate or final consumption, also known as the market clearing condition, we can write output of a country-sector pair as the sum of sales for intermediate and final use over all country-sector pairs. Obtaining the technical coefficients by dividing the use of intermediate inputs by gross output for each pair of

[7] Another important technology that could have been analysed is the development of autonomous cars given that this technology it could potentially have an important impact in the industry in the coming years. See https://ec.europa.eu/growth/tools-atabases/dem/monitor/sites/default/files/DTM_Autonomous%20cars%20v1.pdf for more details. However, this is outside the scope of this analysis.

country-sectors, i.e. $\frac{x_{js}^{kz}}{y^{js}} \equiv a_{js}^{kz}$[8], we can write a country-sector's gross output as follows (corresponding to Equation 21 in the Appendix):

$$y^{kz} = \sum_{j=1}^{N}\left(\sum_{s=1}^{S} x_{js}^{kz} + f_j^{kz}\right) = \sum_{j=1}^{N}\sum_{s=1}^{S} a_{js}^{kz} y^{js} + \sum_{j=1}^{N} f_j^{kz} \tag{1}$$

Using matrix algebra, this expression can be summarised for all country-sector pairs with a system taking into account that $\boldsymbol{f}$ is the ($S$*$N$) x 1 vector of final demands and **A** represents the ($S$*$N$) x ($S$*$N$) global bilateral input-output matrix at the country-sector level.

$$\mathbf{Y} = \mathbf{AY} + \boldsymbol{f} \tag{2}$$

where,

$$\mathbf{Y} = \begin{bmatrix} y^{1,1} \\ y^{1,2} \\ \vdots \\ y^{N,S} \end{bmatrix} \qquad \mathbf{A} = \begin{bmatrix} a_{1,1}^{1,1} & a_{1,2}^{1,1} & \dots & a_{N,S}^{1,1} \\ a_{1,1}^{1,2} & a_{1,2}^{1,2} & \dots & a_{N,S}^{1,2} \\ \vdots & \vdots & \ddots & \vdots \\ a_{1,1}^{N,S} & a_{1,2}^{N,S} & \dots & a_{N,S}^{N,S} \end{bmatrix} \qquad \boldsymbol{f} = \begin{bmatrix} \sum_{j=1}^{N} f_j^{1,1} \\ \sum_{j=1}^{N} f_j^{1,2} \\ \vdots \\ \sum_{j=1}^{N} f_j^{N,S} \end{bmatrix}$$

Rewriting this system using the standard input-output decomposition technique introduced by Leontief (1936, 1941), we find the following expression for nominal output:[9]

$$\boldsymbol{Y} = (\mathbf{I} - \mathbf{A})^{-1}\boldsymbol{f} = \boldsymbol{\Lambda f} \tag{3}$$

where **I** is the ($S$*$N$) x ($S$*$N$) identity matrix, $\boldsymbol{\Lambda} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse matrix and each element $\Lambda_{i,s}^{k,z}$ of $\boldsymbol{\Lambda}$ measures the total of dollars' worth of country-sector *kz* goods required to meet 1 dollar worth of country-sector *is'* final demand. In other words, if we consider the supply chain to produce French final demand in cars, this coefficient would take into account the "infinite" interaction of suppliers needed to produce the final demand of cars.[10]

In order to evaluate the importance of the automobile sector for national economies, we need to focus on the actual production process in more detail. In other words, we need to link the final demand associated with the automobile sector to actual value added and employment (**L**) created within domestic borders. Note that this is consistent with our theoretical framework in the appendix where we assume that output in an industry is a Cobb-Douglas function of quantities of labour and intermediate

[9] This expression is obtained under the assumption that $(\mathbf{I} - \mathbf{A})$ can be inverted (see Miller and Blair, 2009 for more details).

[10] This method relies on the proportionality assumption. In other words, it assumes that the inputs needed to produce a unit of output in a particular country-sector pair are independent to the use of its output.

inputs. Assuming that the value added share of a country-sector's production is the part that is generated by its labour, we can transform the nominal output into employment.[11] For this purpose, we use a requirement vector ($\boldsymbol{\lambda}$) with the same dimensions $SN \times 1$ capturing the number of workers required per value of output in each country-sector pair.[12]

$$\boldsymbol{L} = \hat{\boldsymbol{\lambda}} Y = \hat{\boldsymbol{\lambda}} \boldsymbol{\Lambda} \boldsymbol{f} \tag{4}$$

Using Equation (4), we are able to obtain the labour required to meet a specific final demand. For example, if $\boldsymbol{f}_{2016}^{FR,Cars}$ captures the worldwide final demand for cars sold by France in 2016, Equation (4) allows to compute the labour required in each country-industry in the world to meet this demand. This employment includes labour used in the car industry in France and also in domestic and foreign upstream industries delivering intermediate goods and services to French car producers.

Throughout this analysis, we use the identity of Equation (4) as a basis for evaluating the different aspects of the automobile sector. Matching with the OECD Analytical AMNE input-output database, we use *N*=60 countries including the rest of the world and *S*=34 sectors, which includes our sector of interest "C29-Manufacturing of motor vehicles, trailers and semi-trailers", over the period between 2005 and 2016.[13] We complement this data with employment data Eurostat National Accounts. When looking at the impact in countries outside the EU, our analysis uses the global input-output table provided by WIOD (Timmer et al. 2014, 2015) due the higher coverage of sectoral employment for countries outside the European Union. The WIOD database contains sectoral information capturing the total economy from 2000 until 2014 for 43 countries, as well as a model for the rest of the world.

# 3. ANALYSIS OF PAST AND POTENTIAL FUTURE TRENDS OF THE CAR INDUSTRY

Before we estimate the economic impact of a drop in demand for cars by world consumers, we want to understand the current importance of the car industry and its related sectors for national economies. We will continue by analysing how this importance has evolved over the last years for different countries and sectors in the EU, with a particular focus on France and Germany. This is particularly important for countries like France that have experienced an important reallocation of their car activities in the last decade.

We start by showing the importance of the automobile sector across countries in gross terms.[14] Whereas Figure 1 shows the share of the automobile sector in total national production in 2016, Figure 2 displays the exports of the automotive sector as a share of total exports. We observe that France was among the EU countries where the car industry represented the lowest share of total output and total exports. In Central and Eastern European countries, namely Slovakia, Hungary, Czechia and Germany,

[11] This is consistent with the theoretical framework developed in the Appendix.

[12] A hat indicates a diagonal matrix with elements of the requirement vector on the diagonal.

[13] The Analytical AMNE database includes an additional dimension consisting in a separation between domestic firms and foreign firms. While in this paper we do not exploit this extra dimension, the Analytical AMNE database is chosen over the ICIO database as it is last available year is 2016 instead of 2015.

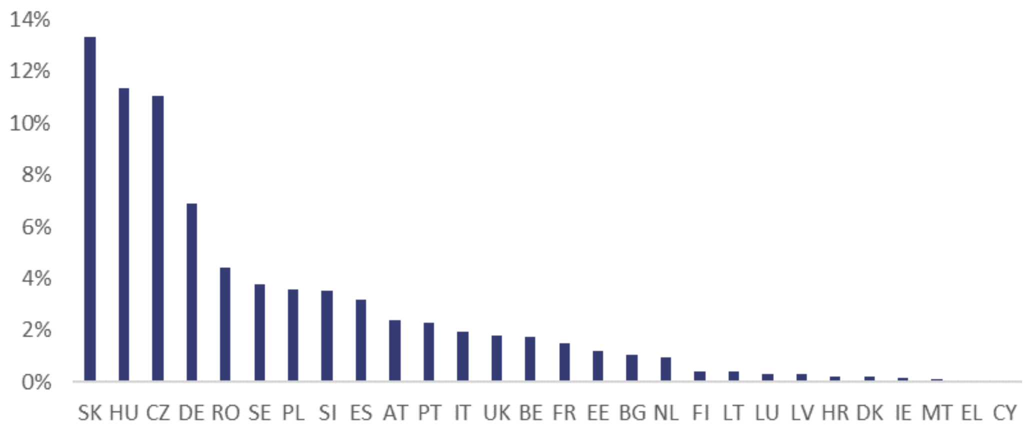
[14] The latest year available in the OECD MNE Input-Output tables is 2016.

the car industry showed a higher share in terms of total output. It is important to highlight that these countries export a high share of their exports to countries outside the EU. This contrasts with other countries like Belgium, France, Italy, Spain, Slovenia, Poland or Portugal where the majority of exports are destined for the EU market.

Consequently, while gross figures give a good indication of the importance of the car sector for the domestic economies, we need to look at value added production (or employment embedded in value added) if we were to evaluate a country's exposure to shocks affecting the car industry. In other words, a country might be producing domestically the last stages of the cars’ value chain, but if the majority of this production relies on foreign inputs, its exposure to shocks in the final demand for cars would be significantly reduced. Figure 3 shows the foreign value added content of the automobile sector as a percentage of the sector's total value added, differentiating between the geographical origin of the inputs. We observe that while in Slovakia and Hungary the automobile industry is economically important (Figures 1 and 2), the domestic value added content of the car production in these countries is limited to 40%. The three largest economies of the EU, France, Italy and particularly Germany show a higher domestic value added share in their production of cars. In terms of the geographical origin of the inputs used in the production of cars, we observe that across EU countries the majority of the inputs originate from other EU countries. This underscores the importance of the EU supply chains for European car producers.

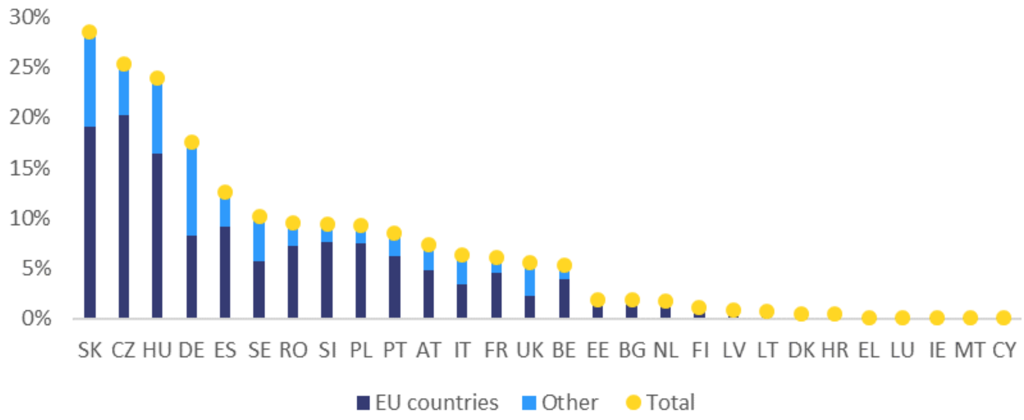
Finally, the demand for cars by final consumers generates value added in the automobile sector but also in other domestic and foreign sectors. Using Equation 4, we obtain the labour (based on value added) required in each country-sector in order to meet world final demand for cars. Figure 4 shows the total domestic value added generated in a country that it is linked to the world final demand for cars, as a percentage of total value added of the country. As in Figure 1, this graph indicates that Slovakia, Czechia, Hungary and Germany are the countries that rely the most on the final demand for cars. France ranks as the 16th country in the EU where the worldwide demand for cars is more important, indicating its relatively limited exposure to a potential shock to overall final demand for cars. In the next subsection, we investigate the evolution of this exposure since the enlargement of the European Union in 2004.

Figure 1: **Share of the automobile sector in total output (% of national output)**



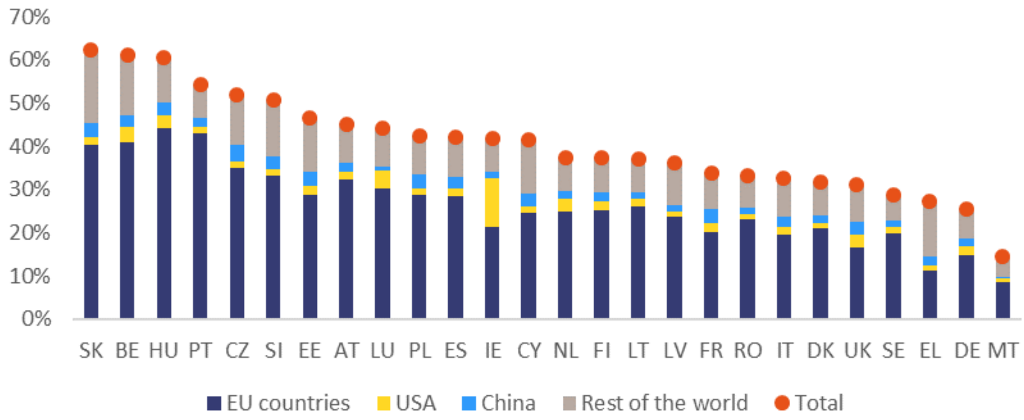

Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts (2016 data).

Figure 2: **Share of exports of the automotive sector in total exports (% of national exports), by destination**



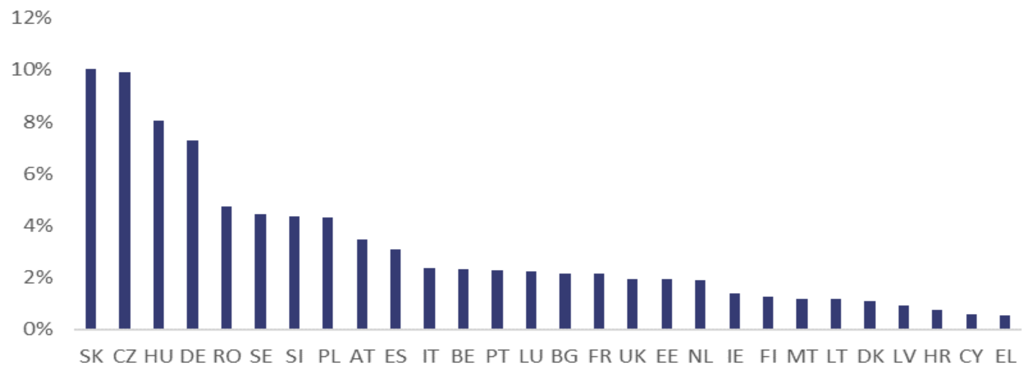

Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts (2016 data).

Figure 3: **Foreign value added content of the automobile sector (% of total sectoral value added), by origin**




Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts (2016 data).

Figure 4: **Total domestic value added generated by world final demand of cars (% of total national value added)**




Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts (2016 data).

### 3.1. QUANTIFYING THE EVOLUTION OF THE IMPORTANCE OF THE CAR INDUSTRY AND ITS INPUTS

To study the importance of the car manufacturing and its related sectors for France and other EU countries, this analysis adapts a technique proposed by Los et al. (2015) and Feenstra and Sasahara (2017).[15] This methodology allows to decompose different explanatory factors behind the evolution of the importance of the car sector across countries, evaluated in terms of employment and based on its value added. In this respect, we are interested in analysing how countries are affected by past worldwide changes in three main elements: (1) world final demand for cars ($\boldsymbol{f}$), (2) global input-output structures in the production of cars ($\boldsymbol{\Lambda}$) and (3) sectoral production structures ($\boldsymbol{\lambda}$). First, we look at the change in the labour induced by the observed evolution in the three main elements, measured by the following expression:[16]

$$\Delta \boldsymbol{L}^{cars} = \hat{\boldsymbol{\lambda}}_{2016}\boldsymbol{\Lambda}_{2016}\boldsymbol{f}_{2016}^{cars} - \hat{\boldsymbol{\lambda}}_{2005}\boldsymbol{\Lambda}_{2005}\boldsymbol{f}_{2005}^{cars} \quad (5)$$

where the first term measures the employment associated with the production for world final demand for cars in 2016 and the second term measures employment associated with the production for world final demand for cars in 2005. The positive (negative) difference between these two terms measures the employment created (reduced) due to the observed change in the three main elements identified above.

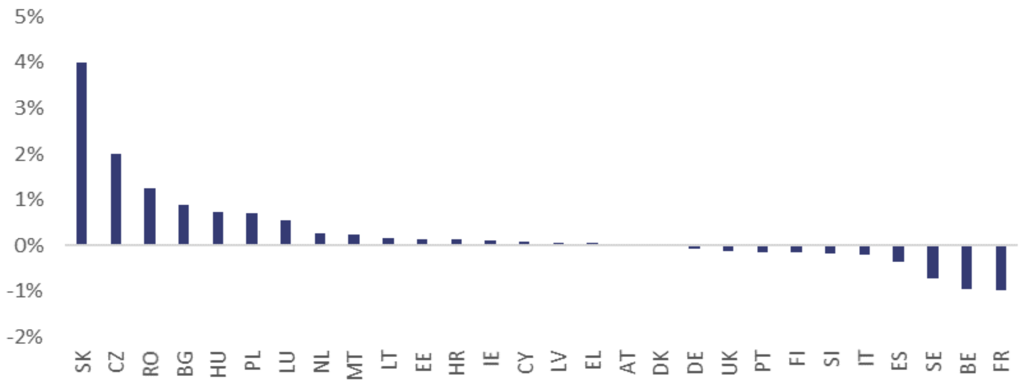
Figure 5 shows the evolution of employment as a result of changes in the three combined elements for each country in the EU, displayed as a share of the country's aggregate employment in 2005. In particular, it shows that relocation of total production of cars has negatively affected France, Belgium, Sweden, Spain and Italy. This fall in production of cars can be explained by different factors. For instance, while French brands have offshored its production of cars to third countries affecting the production within the French geographical borders (see Maravall-Rodriguez and Küffel (2018) for evidence), the effect on the Belgium economy could indicate that as an assembler of cars, it could not compete anymore with other countries in the single market with relative lower manufacturing costs. On the other hand, the countries that have seen an increase in the importance of the car industry are Slovakia, Czechia, Romania, Bulgaria and Hungary. For other countries such as Germany or the UK, the share is only slightly lower or almost stable. Given that the car industry uses inputs from many

[15] Other related literature investigating inter-sector and international linkages in global value chain include among others: Johnson and Noguera (2012), Foster-McGregor and Stehrer (2013), Timer at al. (2014), Timmer et al. (2015)

[16] This approach is an ex-post analysis. It uses exogenous input-output variables observed between 2005 and 2016. It analyses value added and employment without explicitly modelling the interaction of prices and quantities, which are particularly important in Computable General Equilibrium models. Contrary to our methodology, the main disadvantage of these models is that they require econometric estimation of various parameters of production and demand functions. This is particularly relevant in this type of setting where intermediate inputs can be sourced from domestic and foreign market, which dramatically increases the number of parameters. This framework relies on a reduced form model, where input costs shares and labour requirements are known and we assume that these do not change for different levels of demand. In addition, this methodology relies on the proportionality assumption, which means that the technology requirement is the same for all outputs of an industry. Finally, the input-output database used in this project is expressed in current US dollars implying that the technology requirements coefficients are sensitive to inflation. In those cases where the technology coefficient and final demand levels are both affected by inflation, the price changes will cancel out in the decomposition unless price developments of cars exported to market foreign markets diverge from price changes of cars for domestic consumption.

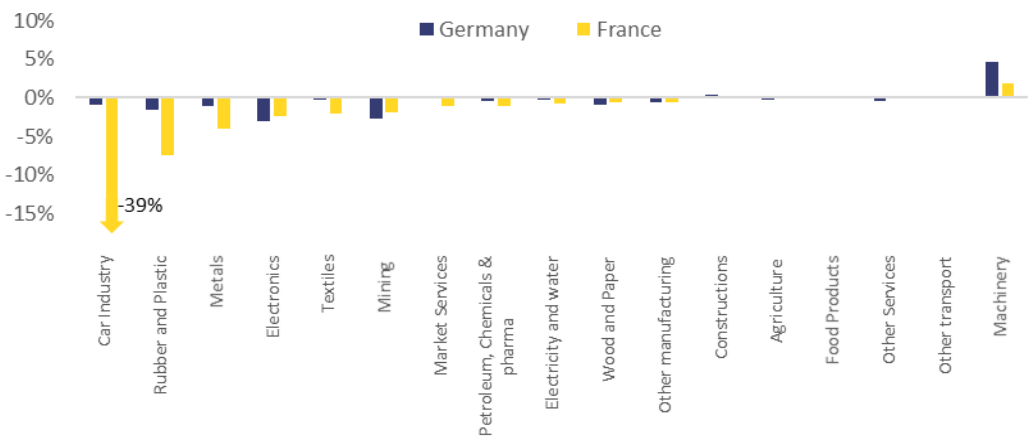
domestic sectors, Figures 6 shows the aggregate effect for France and Germany from a sectoral perspective. Whereas the contribution to the machinery sector to the car industry has gained importance in France in the last decade, partly explained by the increased automation experienced in the car sector, the decline in the overall importance of the car industry in France is mainly the result of a decrease in the inputs from the car industry itself. This is complemented by the decline in other sectors like rubber and plastic, metals and electronics and computers. On the other hand, Germany has maintained its position in the car industry relying on inputs from the machinery sector, while it has decreased its presence in all the other sectors used as inputs, with electronics and computers, mining, rubber and plastic or metals being the most affected German sectors. This finding suggests that carmakers in France and Germany have relied on different strategic choices. While French carmakers have traditionally relied much more on offshoring the final production, Germany seems to have retained much more assembly at home, while offshoring intermediates to neighbouring countries. This is in line with the observation by Maravall-Rodriguez and Küffel (2018), who observe that while production in the final production of cars has dropped in France, global production of French brands has not decreased in the last two decades.

Figure 5: **Change in employment (as % of total employment in 2005) due to changes in the three main elements**




Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

Figure 6: **Change in employment (as % of total sectoral employment in 2005) across French and German sectors due to changes in the three main elements**




Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

Next, we decompose each of the effects of the three main elements identified above: (1) world final demand for cars ($\boldsymbol{f}$), (2) global input-output structures in the production of cars ($\boldsymbol{\Lambda}$) and (3) sectoral production structures ($\boldsymbol{\lambda}$). The geographical reallocation of car production across countries has important implications. For example, if the demand for French car brands increases worldwide, those countries producing French brands will benefit, as well as those country-sectors producing inputs ultimately used in French car brands.

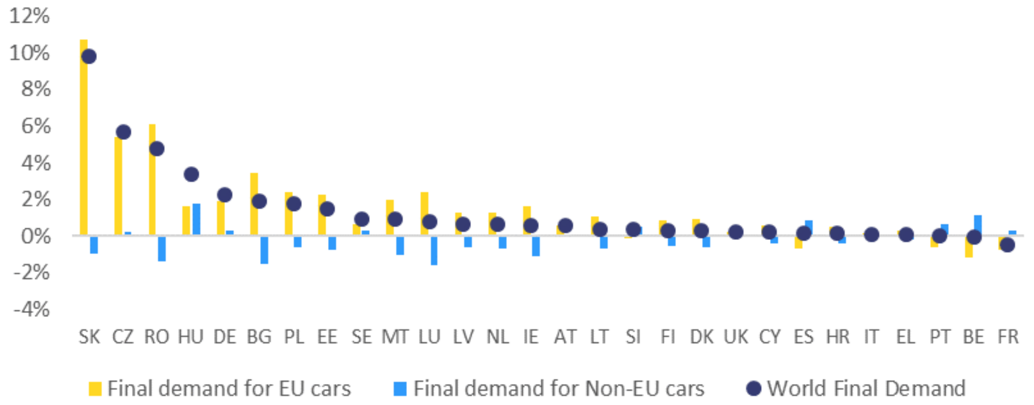
For this purpose, we quantify the employment effect for each country-sector pair originating from a change in world demand for cars between 2016 and 2005.

$$\Delta \boldsymbol{L}^{demand,cars} = \hat{\boldsymbol{\lambda}}_{2016}\boldsymbol{\Lambda}_{2016}\boldsymbol{f}_{2016}^{cars} - \hat{\boldsymbol{\lambda}}_{2016}\boldsymbol{\Lambda}_{2016}\boldsymbol{f}_{2005}^{cars} \qquad (6)$$

On the right hand side of Equation (6), the first term measures the actual employment induced by the final demand for cars as observed in 2016, whereas the second term is the employment in a hypothetical world where final demand in the car industry stayed at the same level as in 2005. The positive (negative) difference between these two terms measures the employment created (reduced) by the change in demand for cars. This effect can be decomposed further into the employment effect originating from the change in demand for EU as well as non-EU produced cars. Figure 7 shows that France and Belgium appear to be the countries where employment demand decreased the most as a result of the variation in global final demand in the car industry, indicating that they have lost importance due to the relocation of the origin of the production of cars. On the other hand, countries like Slovakia, Czechia, Romania or Hungary have clearly benefited from the evolution in the final demand for cars over the time horizon considered. This can be partly explained by the fact that these regions have seen increases in their GDP per capita and consequently, their demand for cars has increased. Among the largest countries in the EU, Germany is one of the biggest beneficiaries from the evolution of the world trend in final demand. The evolution of the final demand (blue part) for cars produced by non-EU countries had a heterogeneous impact across EU countries. We observe a positive effect in France, Belgium, Portugal and Spain as a result of the change in demand for European cars. Contrary, the main positive effect for the majority of the new European member states originates from the change in demand for EU cars (green part) over the last decade.

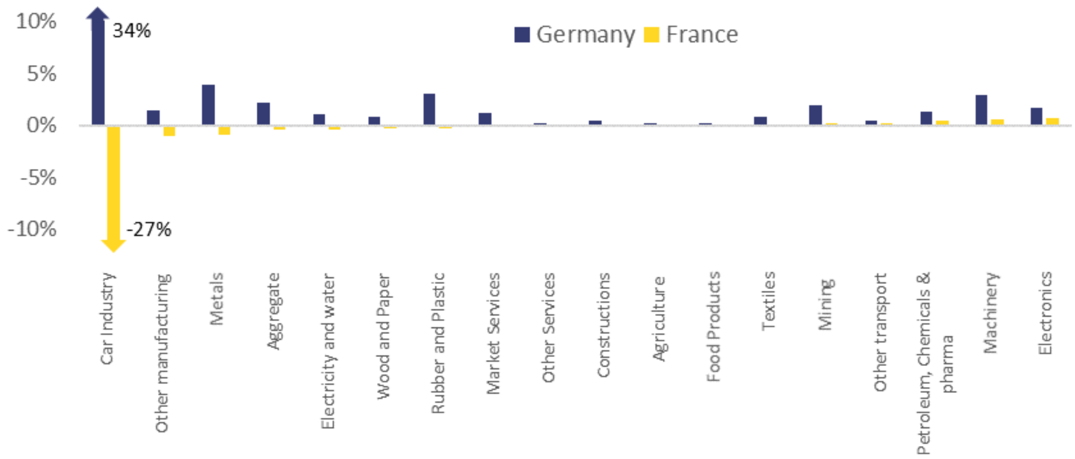
The aggregate impact of changes in the global demand for cars can be further decomposed across their input sectors. Figure 8 disaggregates the total employment effect for the French and German economy into sectoral effects. In France, we observe that the main industry negatively affected by the change in global demand for cars is the car industry itself. However, there are other sectors used as inputs in the production of cars, such as metals or other manufacturing, that they have seen their total employment demand decrease by approximately 1%. On the other hand, other domestic French sectors such as electronics and computers, machinery and petroleum, chemicals and pharmaceuticals have benefited from global reallocation of the final production of cars. In comparison, Germany has only benefited from the global reallocation of final demand over the last decade: on the top of the German car industry itself, most of the German sectors involved in the car production have increased the employment demand by more than 1%.

Figure 7: **Change in employment (as % of total employment in 2005) due to changes in final demand for cars**




Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

Figure 8: **Change in employment (as % of total sectoral employment in 2005) across French and German sectors due to changes in final demand for cars**



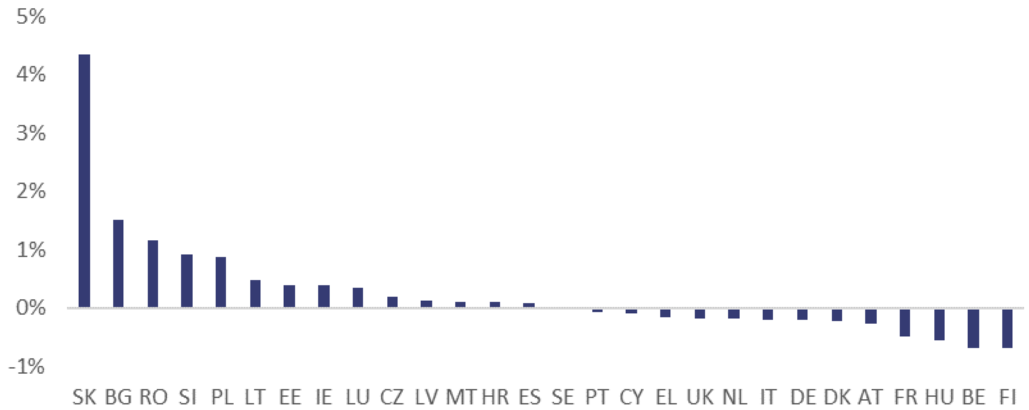

Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

While the previous measure takes into account changes in the final demand for cars, it does not consider neither possible changes in the global input-output matrix nor changes in the sectoral production functions. While a country might face only minor changes in the demand for cars, it might substantially gain or lose participation in the supply chain of cars. The next measure computes the effect on employment of changes in the global car supply chains. In other words, it measures the change in employment demand in each country-sector pair, keeping global final demand for cars fixed at its 2016 level, in a hypothetical world where global supply chain retained their 2005 structure.

$$\Delta \boldsymbol{L}^{I-O,cars} = \hat{\boldsymbol{\lambda}}_{2016}\boldsymbol{\Lambda}_{2016}\boldsymbol{f}_{2016}^{cars} - \hat{\boldsymbol{\lambda}}_{2016}\boldsymbol{\Lambda}_{2005}\boldsymbol{f}_{2016}^{cars} \tag{7}$$

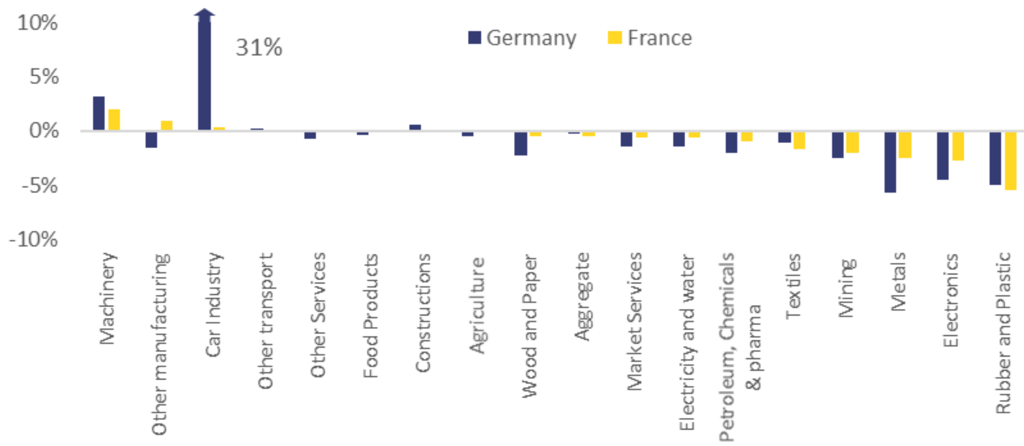
Figure 9 displays the change in labour demand (shown as a share of employment in 2016) resulting from the change in the international supply chains since 2005. A positive effect indicates that the country has increased its participation in the global supply chains of the final production of cars. On the contrary, a negative effect indicates that the participation of the country in the global value chains of cars has declined since 2005. The main observation is that with the exception of Hungary, countries that joined the European Union in 2004 have particularly increased their participation in the global supply chains of cars. Conversely, older members states such as Finland, Belgium, France, Austria, Denmark or Germany have seen a decrease in their importance in the particular sector. Other countries like Spain, Sweden or Portugal have seen their role in the global value chains of cars broadly unchanged. Figure 10 disaggregates the total employment demand effect into sectoral effects for France and Germany. In both countries, the decrease in the supply chain participation in the production of cars can be observed across most sectors, with the most pronounced employment losses in the rubber and plastic, as well as in electronics and computers. The machinery and the car industry itself are exceptions, especially in Germany, that benefit in terms of new employment due to the change in global production structures.

Figure 9: **Change in employment (as % of total employment in 2005) due to changes in global car supply chains**




Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

Figure 10: **Change in employment (as % of total sectoral employment in 2005) across French and German sectors due to changes in global car supply chains**



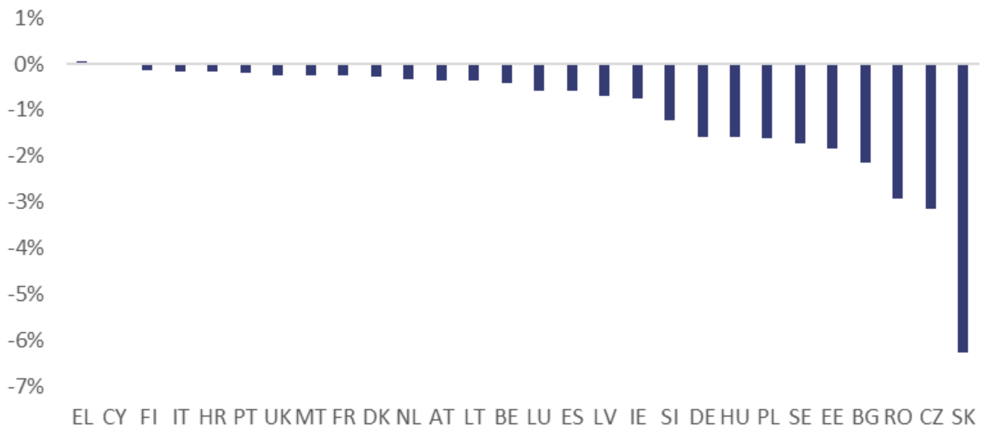

Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

Finally, it has been documented that the labour share on how country-sectors produce has been declining since the 1990s due to among other factors, an increase in robotisation.[17] The next measure captures the employment effect originating from changes in the sectoral production functions. It measures the potential reduction (increase) of employment in a country-sector pair by fixing the flows of goods as in 2016, including final and intermediary, but with a hypothetical world where sectoral labour shares remained fixed as in 2005.

$$\Delta \boldsymbol{L}^{prod,cars} = \hat{\boldsymbol{\lambda}}_{2016}\boldsymbol{\Lambda}_{2016}\boldsymbol{f}_{2016}^{cars} - \hat{\boldsymbol{\lambda}}_{2005}\boldsymbol{\Lambda}_{2016}\boldsymbol{f}_{2016}^{cars} \tag{8}$$

A negative number of this indicator shows, everything else equal, the employment affected by the evolution of labour productivity in every country-sector pair which is used to produce its domestic and foreign final demand for cars. A lower number can be interpreted as a higher labour productivity gain experienced in the country throughout the supply chain of automobiles. It is important to highlight that this term includes the evolution of labour productivity in each sector part of the supply chain of automobiles. Figure 11 shows that technological progress is particularly visible in Member States that entered the EU in 2004. Among the biggest EU member states, Germany observes the most important progress in terms of labour productivity of sectors used to produce cars.

Figure 11: **Change in employment (as % of total employment in 2016) due to changes in labour inputs**




Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

### 3.2. QUANTIFYING THE EFFECT OF A NEGATIVE DEMAND SHOCK IN THE CAR INDUSTRY

Using Equation (4), we can quantify the impact of a change in world final demand for cars on employment ($\boldsymbol{L}$) in the EU. Keeping global supply chain structures constant, the impact in terms of employment originating from a final demand shock for cars by consumers in different world regions can be computed as follows:

$$\Delta \boldsymbol{L} = \hat{\boldsymbol{\lambda}}_{2016}\boldsymbol{\Lambda}_{2016}\boldsymbol{f}_{t=shock}^{cars} - \hat{\boldsymbol{\lambda}}_{2016}\boldsymbol{\Lambda}_{2016}\boldsymbol{f}_{2016}^{cars} \tag{9}$$

[17] See the review done by the OECD and the ILO for more details on stylised facts. This finding is also consistent with the increasing sourcing of machineries found above.

Given the global nature of the car production, we expect negative direct and indirect effects in different country-sector pairs as a result of a decrease in the final demand by a particular country. For example, if final demand for cars decreases in France, Spanish steel used in a German car exported to France will be negatively affected. In this analysis, we will decompose the effect of a hypothetical 10% decrease in final demand for cars by world consumers, distinguishing between the effect originating from a decrease in the domestic and foreign final demand. The effect that originates from foreign countries is further decomposed between EU countries, important world economies such as the US and China, and the rest of the world. The size of the shock to the final demand was chosen for simplicity of exposition and can be modified without changing the overall conclusions of the analysis given that our results vary linearly with the size of the final demand shock, i.e. doubling the demand shock in the car sector, doubles the value added losses (see Annex 2).

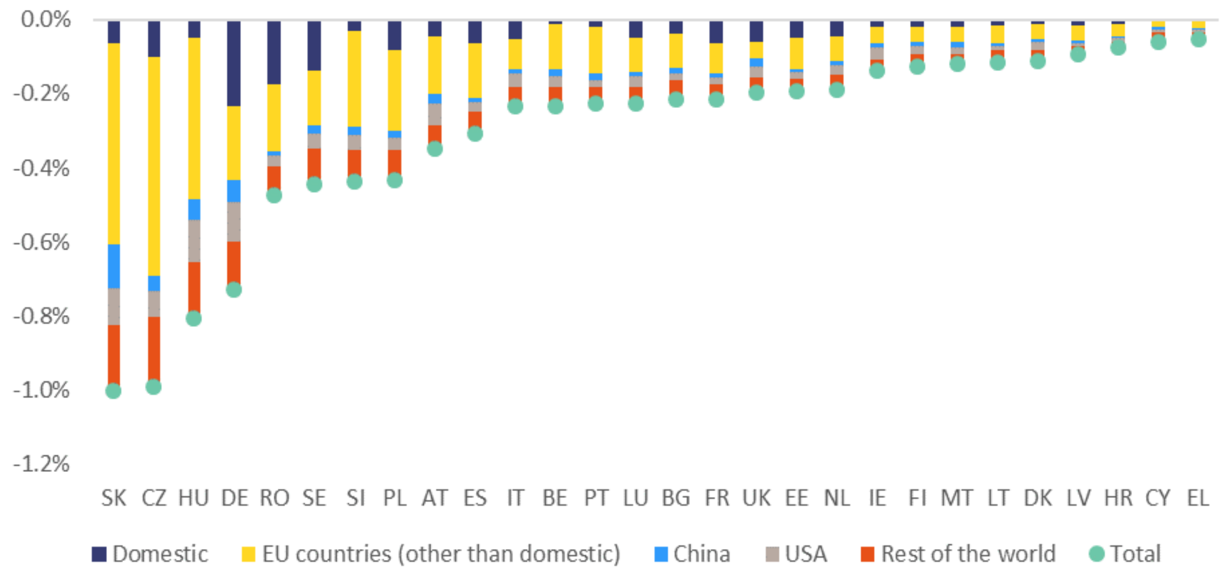
Figure 12 depicts the changes in the demand of total employment induced from a shock to the final demand of cars, as a share of total employment in 2016. The total change in employment includes both direct losses in the automotive sector and indirect effects in sectors used in the production process of cars. Central and Eastern European countries are found to be the most exposed to a negative world demand shock in cars, i.e. Czechia, Slovakia and Hungary, with a major part of the total employment loss coming from a decrease in foreign demand, notably coming from other EU countries, rather than domestic demand. This reflects the importance of the automotive sector in these countries and their strong participation in European value chains, notably in those of Germany. In this respect, Germany would also experience an important loss as a share of its total employment (0.7 %), driven by the weight of the automobile sector in the German economy. This translates into the largest drop in absolute terms observed in the European Union [216 thousand workers[18] could be affected]. In Germany, a negative effect from the shock stems more than in other large EU car producers from the domestic market, pointing to the importance of the domestic market. While the effect originating from a demand shock in other EU countries is slightly lower in Germany than in other in other large EU car producers, the effect of the shock from extra-EU markets is relatively larger in Germany. In particular, it seems to rely more on US and Chinese demand. In absolute terms, France would experience the fourth largest drop in the European Union [48 thousand workers], after Germany, Poland and Italy. As a share of total employment 0.21% of workers would be affected, placing France in the middle of the EU ranking. The result is driven by the relatively lower weight of the automobile sector in the French economy. Compared to Germany, French employment would be more affected by a negative shock to European demand. This suggest that France seems to be less exposed to a shock in extra-EU markets.

Figure 13 displays the impact of the demand shock on employment demand in the automotive sector as a share of the sector's total employment. Among large automotive producers, France would be particularly exposed to a shock on world final demand for cars with a drop of around 9% of its total sectoral employment, of which 7% originates from the EU markets. This shows its relatively strong reliance on European demand. In comparison, the impact in Germany would be 8%, of which 5% originates from the EU. This suggests that the German automotive sector relies relatively more on demand for cars from outside the EU. Figure 14 shows the impact in terms of employment of a demand shock on domestic sectors in France and Germany. While the domestic sectors mostly involved in the car production are common in both countries (Metals, Rubber and Plastic, Machinery),

[18] Note that the result is based on a purely static exercise: any employment substitution effects or adjustment of production processes are not taken into account.

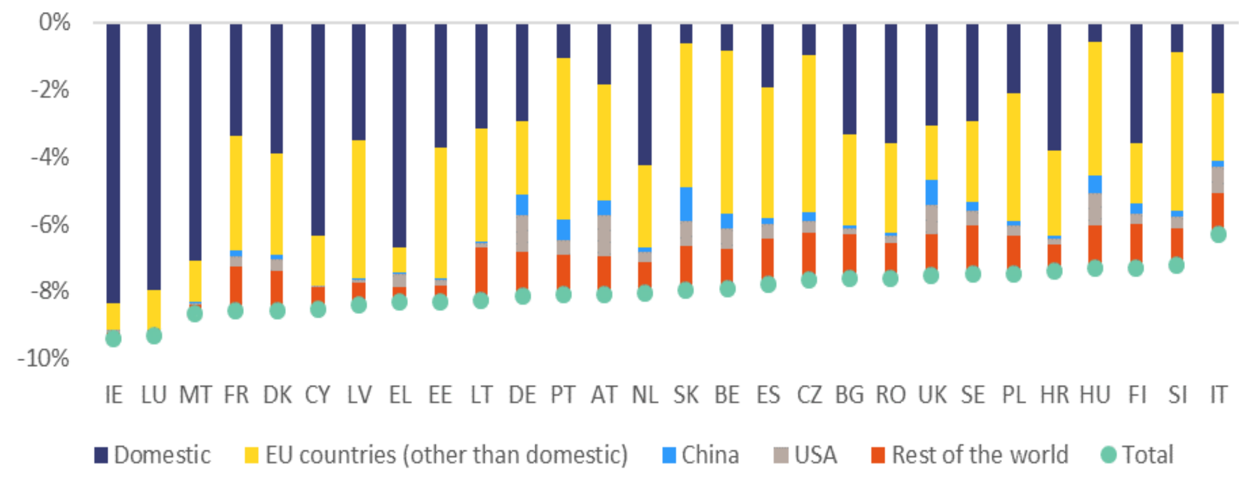
German employment demand in all the sectors would be more affected by a shock, pointing to a relatively stronger reliance of German sectors on the automobile industry. For instance, whereas German employment demand will decrease by 1.35% in metal industries and 0.9% in machinery sectors, France would only observe a drop of 1% and 0.7%, respectively.

Figure 12: **Change in national employment (as % of total employment in 2016) due to a 10% decrease in demand for cars by world consumers, by origin of the demand**




Source: Own calculations based on OECD Input-Output Tables and Eurostat National Account.

Figure 13: **Change in employment in the automotive sector (as % of total sectoral employment in 2016) due to a 10% decrease in demand for cars by world consumers, by origin of the demand**




Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

Figure 14: **Change in employment in France and Germany (as % of total sectoral employment in 2016) due to a 10% decrease in demand of cars by world consumers, by sector**


Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

## 3.3. THE TRAINSITION TOWARDS ELECTRIC VEHICLES

With the exception of Germany, we observed a relocation in the car- related industries away from the old EU member states in recent years. However, the car industry is entering into a phase of substantial change, creating new challenges as well as opportunities. According to the Global Automotive Executive Survey conducted by the auditing and consultancy firm KPMG in 2019, an important challenge identified in the car industry relates to the development of the electric vehicle.[19] Recent trends show that while 17,000 electric cars were on the world's roads in 2010, the number has sharply increased to 7.2 million in 2019, of which 47% were in China and 24% in Europe. In parallel, electric cars represented 2.6% market share in worldwide car sales and 3.5% in European car sales in 2019. In terms of worldwide sales, 2.1 million electric car sales in 2019 represent a 6% growth rate with respect to 2018.[20] While determining the winners and losers from this transition remains a speculative exercise, the magnitude of the potential impact of this transformation and the effect on the global supply chains of cars can be understood by looking at the value added originating from the sector electronics and computers.[21] Figure 15 shows that, in 2016 in the EU, this sector represented approximately 2% of the total value added of a car. Figure 16 shows a cross-country comparison of the share of electronics and computers in the production of cars. The share of electronics exceeded 5% of the total value added of cars only in the US and South Korea. In the EU, the countries with the highest share of electronics and computers in the production of cars are Hungary and Czechia. France ranks in an average position but with a higher share than in Germany.

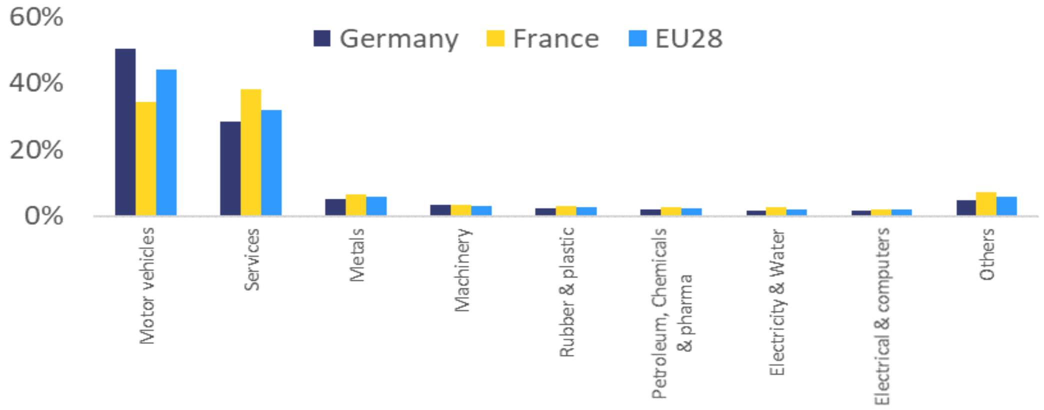
[19] Global Automotive Executive Survey 2019 (See https://home.kpmg/xx/en/home/insights/2019/01/global-automotive-executive-survey-2019.html for more details).

[20] See https://www.iea.org/reports/global-ev-outlook-2020 for more details.

[21] We acknowledge that other important inputs for the production of the electric vehicles might not be included in the electric sectors considered in this analysis. For instance, an important input for the production of batteries is lithium, which is part of the chemical sector. This being said, we do not have any evidence that this will change the main conclusions of the analysis.

The development of the electric vehicle might have important economic implications, as some countries will gain economic activity whereas others will lose from the potential adoption of a higher share of electronic components in the production of cars. In this analysis, we are going to describe the potential first-mover advantage of each country in the sectoral transformation towards electric cars. Indeed, Mueller (1997) argues that an important empirical regularity of a product or industry's life cycle is that the one or two firms that eventually become industry leaders tend to be among the first to enter the industry.[22] To identify the countries that could have a potential first-mover advantage in the transformation of cars towards electric vehicles, we look at the main producers of the electronic components embedded in the world production of cars. In other words, this analysis takes into consideration that the increasing importance of the electronic content of cars is an existing trend, but the role of these components will accelerate with the upcoming industry-wide shift towards electric vehicles. Consequently, those countries highly present in the production of the electronic content of cars will have a clear comparative advantage if the radical change towards the electric car materialises. Figure 17 shows that the largest contributors of these electronic components in the global supply chains of cars are China and the US, followed at a long distance by the EU27, Japan and Korea.[23] [24]Germany and Italy are the only member states in the EU27 that enter in the top-10 ranking of countries with the highest representation. Taking these figures as a potential indicator of the comparative advantage of each country regarding the transformation of the industry, we can conclude that France is arguably lagging behind the main leaders. Finally, Figure 18 shows that car producers across the EU rely heavily on electronic parts produced within the EU.

Figure 15: **Sectoral contribution to the total VA of motor vehicles (% of total VA of cars)**



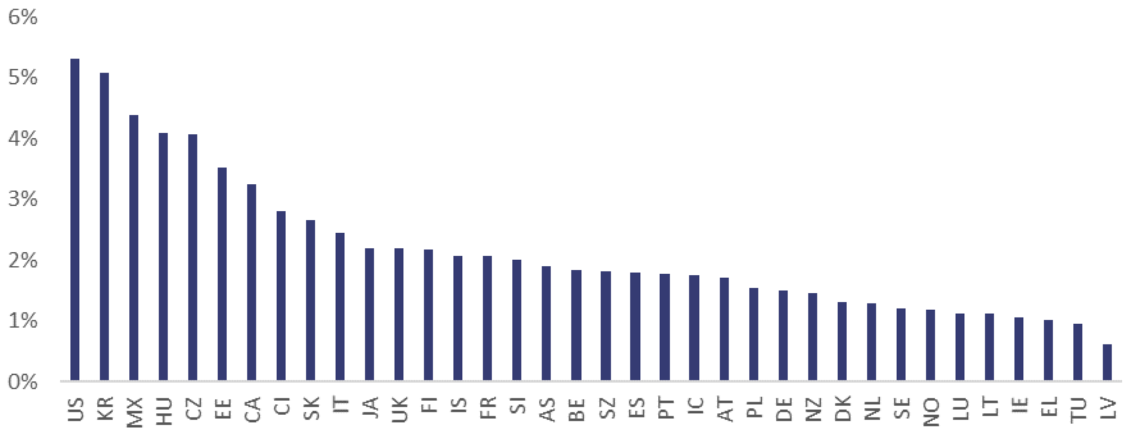

Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

[22] We acknowledge the limitations of predicting the future based on a description of some indicators describing the first-mover advantage. In this respect, Suarez and Lanzolla (2005) argue that the likelihood of gaining first-mover advantage depends on factors such as the pace at which the technology of the product is evolving and the pace at which the market for that product is expanding.

[23] We use Nace rev. 2 C26 (Manufacture of computer, electronic and optical products) and Nace rev. 2 C27 (Manufacture of electrical equipment) to define the electronic part of the car. Indeed, this includes the manufacture of batteries.

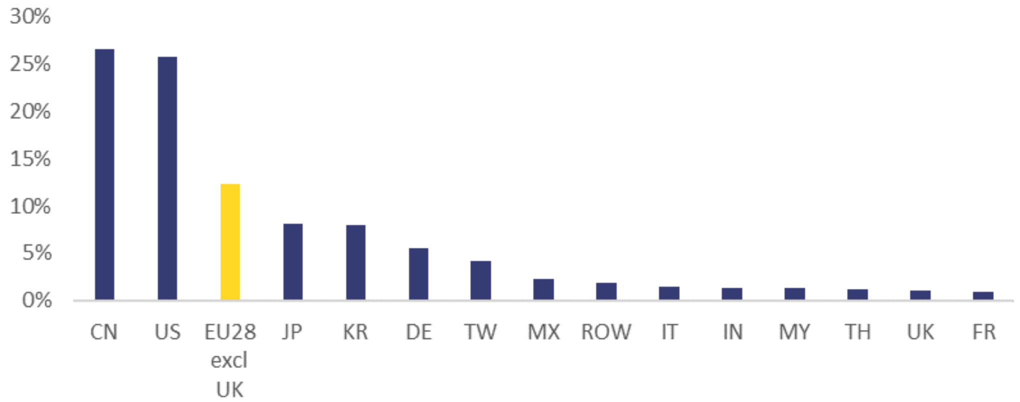
[24] This finding is consistent with the nationality of the biggest producers of electric vehicles. According to LMC Automotive, Tesla is the biggest producer with 220,000 electric cars in 2018, roughly 70,000 more than its closest competitor, the Chinese State-owned BAIC Group. Other indicators consistent with this finding is the number of electric vehicle chargers by country. According to IEA, China (with 37%) and US (24%) are the main countries in terms of private electric vehicles slow chargers. In terms of public accessible chargers, China is clearly in the lead with 52% of worldwide publicly accessible electric vehicle slow chargers and 82% of electric vehicle fast chargers.

Figure 16: **Share of electronics (% of total VA in 2016) in the final production of cars**



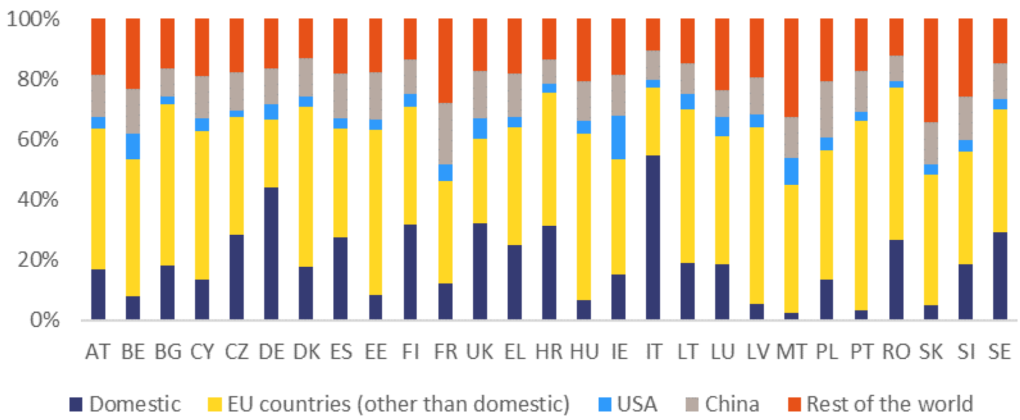

Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

Figure 17: **Share of global electronics production used in cars in 2016**




Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

Figure 18: **Origin of electric parts used in the car sector (% of total electric parts)**




Source: Own calculations based on OECD Input-Output Tables and Eurostat National Accounts.

# 4. CONCLUSION

Production processes in the car industry are particularly fragmented across sectoral and national boundaries. Consequently, using conventional statistics in gross terms that do not consider the industry's interlinkages with other national and international sectors may give a distorted picture. In this respect, this paper takes these national and international sectoral interlinkages seriously in order to analyse various aspects of the car industry across various EU countries.[25]

The first aim of this analysis was to evaluate and decompose the drivers behind the level and past evolution of the role of the automobile sector and its inputs in France, Germany and other EU countries. In this regard, we observe that in 2016, France was among the EU countries where the car industry represents the lowest weight in its economy both in gross and value added terms. This is the result of an evolution of the last decade where a particularly important relocation of car production to other regions in the EU has taken place. While the automobile sector has maintained its relative economic importance in Germany, the biggest beneficiaries in the EU from changes in the industry are those Member States that have joined since 2004, such as Slovakia, Czechia, Romania, Bulgaria and Hungary. Nevertheless, among these countries, there is a high heterogeneity in the causes behind these gains. For example, Hungary gained particularly from the geographical relocation of the production of cars but saw a decrease in its participation in the global supply chains of cars.

The second part of the analysis predicts the potential impact to EU domestic economies resulting from a simulated 10% shock to world final demand for cars. In order to evaluate the potential impact to domestic economies, the sector’s national and international supply chains need to be taken into consideration. In other words, a demand shock in the car sector of a particular country affects multiple sectors located in various countries. Intuitively, countries where the car sector and its inputs represent a high share of its aggregate economy are likely to be more affected. However, this effect is not common across different sectors and there are differences related to countries’ exposure to domestic and foreign markets. For example, while in Czechia, Slovakia and Hungary most of the potential impact stems from a potential drop in the demand for cars by other-EU consumers, Germany and France see their domestic economies as the main drivers behind this potential drop. In addition, evaluating the impact at a sectoral level, we observe differences among member states. For example, the car industry in France is particularly affected compared to other countries such as Hungary, Slovakia or Germany. This means that the impact of a drop of 10% in the world demand for cars can only be analysed by looking at global supply chains, as other sectors used as inputs are also affected.

Finally, we analysed a hypothetical industry-wide shift towards electric vehicle production, which could have important economic implications given the small share of electronics in the current car production process. If this sectoral transformation materialises, we could observe winners and losers across countries. This is due to the potential reduction in the use of their components in the production process of cars using combustion engines. In this analysis, we find evidence that suggest that the EU is lagging behind China and the US when it comes to the industry shift towards electric vehicles. China and the US seem to have a first-mover advantage given that they are the largest contributors of electronic components in the global supply chains of cars, followed by the EU at a long distance.

[25] While this analysis focus on the car industry, this kind of analysis can of course be applied to other sectors.

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# ANNEX I

The theoretical micro-foundations of the methodology developed in this paper are based on a framework developed by Connell, Simons and Vandenbussche (2017). The CES nests on the production and the consumption side use the Armington assumption, which means that goods produced by different sources are imperfect substitutes simply because of their origin. This way, similar goods from different countries can coexist in a destination market.[26] Consumers and producers substitute between goods from different countries based on the sector's trade elasticity. They have a love-for-variety and prefer to consume positive amounts of each available variety.

Throughout the theoretical model, superscripts represent the origin and subscripts show the destination of the goods and services. For instance, $X_{FR,car}^{FR,services}$ refers to the intermediate use of services from France used as inputs by the French car industry. Another important notation refers to country aggregates where, for example, demand for labour by French cars is expressed by $L_{FR,car}$. Countries are denoted by *i*, *j* and *k* and sectors by *r*, *s* and *z*. Real quantities are expressed by upper-case symbols and lower-case symbols denote their nominal counterparts.

**Behaviour of consumers**

A representative consumer in country $k$ derives its utility from consuming quantities of an aggregate final good $F_k$ . This is a Cobb-Douglas combination of quantities $F_k^s$ consumed of final goods from all sectors $s \in S$, with $\alpha_k^s$ being the share in total expenditure. For example, consumers get utility from consuming an aggregate "basket" made of cars, clothes, services among other products. The sector-specific final good $F_k^s$ is a CES aggregate across all countries the good can be purchased from where $\sigma_s > 1$ is the elasticity of substitution between the countries of origin within sector *s*.[27]

$$U_k = F_k = \prod_{s=1}^{S} [F_k^s]^{\alpha_k^s} \tag{10}$$

$$F_k^s = \left[\sum_{i=1}^{N} [F_k^{is}]^{\frac{\sigma_s - 1}{\sigma_s}}\right]^{\frac{\sigma_s}{\sigma_s - 1}} \tag{11}$$

**Behaviour of producers**

A given country-sector pair produces output ($Y^{kz}$) using a Cobb-Douglas technology combining labour ($L_{kz}$) and intermediate inputs ($X_{kz}$), where $\beta^{kz}$ captures the share of intermediate expenditures in total sales of country *k*'s sector z.

$$Y^{kz} = (L_{kz})^{1-\beta^{kz}} (X_{kz})^{\beta^{kz}} \tag{12}$$

[26] This is consistent with the level of aggregation (Nace Rev. 2) of the OECD Analytical AMNE input-output database.

[27] For simplicity, this sector-specific elasticity of substitution is assumed to be the same across all countries *k*.

The intermediate goods composite is a Cobb-Douglas combination of intermediate goods from all sectors $s \in S$, where $X_{kz}^{s}$ denotes the real aggregate demand of intermediates from sector *s* by country *k*'s sector *z* and $\gamma_{kz}^{s}$ is its share in total expenditures on inputs.

$$X_{kz} = \prod_{s=1}^{S} [X_{kz}^{s}]^{\gamma_{kz}^{s}} \tag{13}$$

The sector-specific intermediate good is a CES aggregate across all countries the input can be purchased from, where $\rho_s > 1$ is the elasticity of substitution between the countries of origin within the specific sector *s.*[28]

$$X_{kz}^{s} = \left[\sum_{i=1}^{N} [X_{kz}^{is}]^{\frac{\rho_s - 1}{\rho_s}}\right]^{\frac{\rho_s}{\rho_s - 1}} \tag{14}$$

**Utility and profit maximisation**

The price of labour in country *k* sector *z* is denoted by $w_{kz}$ and the price of output is represented by $p^{kz}$. The iceberg-type trade barrier is denoted by $\tau_j^{kz}$, which captures any extra cost a country-sector pair must incur in order to satisfy demand in a foreign country. Firms maximise profits by choosing labour and inputs and households maximise utility by choosing final demand subject to their budget. This is given by the income from supplying labour to each sector *z* in country *k*, $\left(I_k = \sum_{z=1}^{S} w_{kz} L_{kz}\right)$. In this model, firms and households take wages and goods prices as given. From this assumption, the optimal nominal counterparts can be obtained. For example, nominal output of country *k* sector *z* is represented by $y^{kz} \equiv p^{kz} Y^{kz}$. The CES price index in country *k* of final goods from sector *s* equals $P_k^s = \left[\sum_{i=1}^{N} [P_k^{is}]^{1-\sigma_s}\right]^{\frac{1}{1-\sigma_s}}$, the price of the aggregate intermediate input is given by the Cobb-Douglas price index $PI_{kz} = \prod_{s=1}^{S} [P_k^s]^{\gamma_{kz}^{s}}$ where $P_k^s$ is the CES price index in country *k* for intermediate goods from sector s which we assume, for tractability, to be the same as the corresponding price index for final goods (this implies that $\sigma_s = \rho_s$ and that the price of a certain good from sector *s* is the same whether it is sold as an intermediate or a final good). The (FOB) price of output from *kz* equals $p^{kz} = \left(\frac{w_{kz}}{1-\beta^{kz}}\right)^{1-\beta^{kz}} \left(\frac{PI_{kz}}{\beta^{kz}}\right)^{\beta^{kz}}$.

The optimal nominal demands are given by:

$$l_{kz} \equiv w_{kz} L_{kz} = (1 - \beta^{kz}) y^{kz}$$

$$x_{kz} \equiv PI_{kz} X_{kz} = \beta^{kz} y^{kz}$$

$$x_{kz}^{s} \equiv P_k^s X_{kz} = \gamma_{kz}^{s} \beta^{kz} y^{kz}$$

$$x_{kz}^{is} \equiv p_k^{is} X_{kz}^{is} = \tau_k^{is} p^{is} X_{kz}^{is} = \left(\frac{\tau_k^{is} p^{is}}{P_k^s}\right)^{1-\sigma_s} \gamma_{kz}^{s} \beta^{kz} y^{kz} \tag{15}$$

[28] For simplicity, this sector-specific elasticity of substitution is assumed to be the same across all countries k.

$$f_k^{is} \equiv p_k^{is} F_k^{is} = \tau_k^{is} p^{is} F_k^{is} = \left(\frac{\tau_k^{is} p^{is}}{P_k^s}\right)^{1-\sigma_s} \alpha_k^s \sum_{z=1}^{S} (1-\beta^{kz}) y^{kz} \qquad (16)$$

Market clearing requires that the output of a given country-sector pair is consumed, $y^{kz} = \sum_{j=1}^{N} e_j^{kz}$, where nominal gross export flows are given by $e_j^{kz} \equiv f_j^{kz} + \sum_{s=1}^{S} x_{js}^{kz}$**.** Following Anderson and Van Wincoop (2003), gravity equations are obtained for final and intermediate goods exports at the sectoral level, as well as equilibrium price indices.

$$x_{js}^{kz} = \frac{y^{kz} \gamma_{js}^{z} \beta^{js} y^{js}}{y^w} \left(\frac{\tau_j^{kz}}{\prod^{kz} P_j^z}\right)^{1-\sigma_z} \qquad (17)$$

$$f_j^{kz} = \frac{y^{kz} \alpha_j^z \sum_{s=1}^{S} (1-\beta^{js}) y^{js}}{y^w} \left(\frac{\tau_j^{kz}}{\prod^{kz} P_j^z}\right)^{1-\sigma_z} \qquad (18)$$

$$P_j^z = \left[\sum_{k=1}^{N} \theta^{kz} \left[\frac{\tau_j^{kz}}{\prod^{kz}}\right]^{1-\sigma_z}\right]^{\frac{1}{1-\sigma_z}}$$

$$\prod^{kz} = \left[\sum_{j=1}^{N} \phi_j^z \left[\frac{\tau_j^{kz}}{P_j^z}\right]^{1-\sigma_z}\right]^{\frac{1}{1-\sigma_z}}$$

where $\phi_j^z = \sum_{s=1}^{S} \theta^{js} \left(\gamma_{js}^z \beta^{js} + \alpha_j^z (1-\beta^{js})\right)$ measures the importance of goods from sector *z* for producers and consumers in country *j* and the share of country-sector *kz* in world output is given by $\theta^{kz} \equiv \frac{y^{kz}}{y^w}$ . Intuitively this framework explains the bilateral final goods between firms in country-sector *kz* and the consumers in country *j* using some economic factors as shown in Equation 7. These refer to (1) the economic masses of source $y^{kz}$and destination $\sum_{s=1}^{S} (1-\beta^{js}) y^{js}$ relatively to the economic mass of the world $y^w$, (2) the importance of sector *z* final goods in the destination's consumption $\alpha_j^z$, (3) the bilateral trade costs between countries *k* and *j* in sector *z* ($\tau_j^{kz}$), and (4) the outward and inward multilateral resistance terms ( $\prod^{kz}$ and $P_j^z$).

**Including world input-output production linkages**

The direct dollar's worth of inputs from country-sector *kz* per dollar's worth of output of country-sector *js*, also known as the technical coefficient $a_{js}^{kz}$, is obtained by dividing both sides of Equation (6) by *js*' output:

$$\frac{x_{js}^{kz}}{y^{js}} \equiv a_{js}^{kz} = \frac{y^{kz} \gamma_{js}^{z} \beta^{js}}{y^w} \left(\frac{\tau_j^{kz}}{\prod^{kz} P_j^z}\right)^{1-\sigma_z} \qquad (19)$$

Using the market clearing condition and the technical coefficients we obtain:

$$y^{kz} = \sum_{j=1}^{N} \left(\sum_{s=1}^{S} x_{js}^{kz} + f_j^{kz}\right) \qquad (20)$$

$$= \sum_{j=1}^{N}\sum_{s=1}^{S} a_{js}^{kz} y^{js} + \sum_{j=1}^{N} f_j^{kz}$$

Using matrix algebra, this expression can be summarised for all countries and sectors with a system taking into account that $\boldsymbol{f}_j$ is the ($S$*$N$) x 1 vector of country j's final demands and **A** the ($S$*$N$) x ($S$*$N$) global bilateral input-output matrix at the sectoral level.

$$\mathbf{Y} = \mathbf{A}\mathbf{Y} + \sum_{j=1}^{N} \boldsymbol{f}_j \tag{21}$$

where,

$$\mathbf{Y} = \begin{bmatrix} y^{1,1} \\ y^{1,2} \\ \vdots \\ y^{N,S} \end{bmatrix} \qquad \mathbf{A} = \begin{bmatrix} a_{1,1}^{1,1} & a_{1,2}^{1,1} & \dots & a_{N,S}^{1,1} \\ a_{1,1}^{1,2} & a_{1,2}^{1,2} & \dots & a_{N,S}^{1,2} \\ \vdots & \vdots & \ddots & \vdots \\ a_{1,1}^{N,S} & a_{1,2}^{N,S} & \dots & a_{N,S}^{N,S} \end{bmatrix} \qquad \boldsymbol{f}_j = \begin{bmatrix} f_j^{1,1} \\ f_j^{1,2} \\ \vdots \\ f_j^{N,S} \end{bmatrix}$$

Rewriting the system of Equation (15) we find the solution for nominal output taking into account that $\boldsymbol{\Lambda}$ is the known Leontief inverse matrix[29].

$$\boldsymbol{Y} = (\mathbf{I} - \mathbf{A})^{-1} \sum_{j=1}^{N} \boldsymbol{f}_j = \boldsymbol{\Lambda} \sum_{j=1}^{N} \boldsymbol{f}_j \tag{22}$$

where **I** is the ($S$*$N$) x ($S$*$N$) identity matrix and each element $\Lambda_{i,s}^{k,z}$ of $\boldsymbol{\Lambda}$ measures the total of dollars worth of country-sector *kz* goods required to meet 1 dollar worth of *is'* final demand. In other words, if we consider the supply chain to produce French final demand in cars, this coefficient would take into account the "infinite" interactions of suppliers needed to produce the final demand of cars. From Equation 12, we can obtain country *k*'s nominal output in sector *z* substituting for the final value flowing from country-sector *is* to the consumer in country *j*.

$$y^{kz} = \sum_{i=1}^{N}\sum_{s=1}^{S} \boldsymbol{\Lambda}_{is}^{kz} \sum_{j=1}^{N} f_j^{is} \tag{23}$$

$$= \sum_{i=1}^{N}\sum_{s=1}^{S} \boldsymbol{\Lambda}_{is}^{kz} \sum_{j=1}^{N} \left( \frac{y^{is}\alpha_j^s \sum_{r=1}^{S}(1-\beta^{jr})y^{jr}}{y^w} \left( \frac{\tau_j^{is}}{\prod^{is} P_j^s} \right)^{1-\sigma_s} \right)$$

Assuming that the value-added share of a country-sector's production is the part that is generated by its labour, we can transform the nominal output into value added production. Using Equation 3, the value created by country-sector *kz* is captured by the share of labour $1 - \beta^{kz} \equiv v^{kz}$. The total value-added production by country-sector *kz* shown in Equation 14 is affected by the extent to which *kz* contributes to the supply chain of other country-sector pairs to produce its respective total final demand.

[29] Under the assumption that $(\mathbf{I} - \mathbf{A})$ can be inverted.

$$va^{kz} = v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\boldsymbol{\Lambda}_{is}^{kz}\sum_{j=1}^{N}f_j^{is}$$
$$= v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\boldsymbol{\Lambda}_{is}^{kz}\sum_{j=1}^{N}\left(\frac{y^{is}\alpha_j^s\sum_{r=1}^{S}(1-\beta^{jr})y^{jr}}{y^w}\left(\frac{\tau_j^{is}}{\prod^{is}P_j^s}\right)^{1-\sigma_s}\right) \tag{24}$$

## ANNEX II: EVALUATING A SHOCK ON THE FINAL DEMAND

Equation (18) allows to quantify the impact on country-sector *kz*'s value added production $va^{kz}$ of a change in final demand $\mathrm{d}f_j^{is}$:

$$\mathrm{d}va^{kz} = v^{kz} \sum_{i=1}^{N} \sum_{s=1}^{S} \boldsymbol{\Lambda}_{is}^{kz} \sum_{j=1}^{N} \mathrm{d}f_j^{is} \tag{25}$$

Assuming a uniform decrease of *s*% in final demand for cars by consumers worldwide, ceteris paribus, the corresponding change in *kz*'s value added production is found as

$$\begin{aligned} \mathrm{d}va^{kz} &= v^{kz} \sum_{i=1}^{N} \boldsymbol{\Lambda}_{i,cars}^{kz} \sum_{j=1}^{N} \mathrm{d}f_j^{i,cars} \\ &= v^{kz} \sum_{i=1}^{N} \boldsymbol{\Lambda}_{i,cars}^{kz} \sum_{j=1}^{N} \frac{\mathrm{d}f_j^{i,cars}}{f_j^{i,cars}} f_j^{i,cars} \\ &= v^{kz} \sum_{i=1}^{N} \boldsymbol{\Lambda}_{i,cars}^{kz} \sum_{j=1}^{N} (-s * f_j^{i,cars}) \\ &= -s * v^{kz} \sum_{i=1}^{N} \boldsymbol{\Lambda}_{i,cars}^{kz} \sum_{j=1}^{N} f_j^{i,cars} \end{aligned} \tag{26}$$

which indicates the change $\mathrm{d}va^{kz}$ depends linearly on the assumed parameter *s*.

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