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Cars in Europe: Supply Chains and Spillovers during COVID-19 Times

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ABSTRACT: The auto sector is macro-critical in many European countries and constitutes one of the main supply chains in the region. Using a multi-sector and multi-country general equilibrium model, this paper presents a quantitative assessment of the impact of global pandemic-induced labor supply shocks—both directly and via supply chains—during the initial phase of the COVID-19 pandemic on the auto sector and aggregate activity in Europe. Our results suggest that these labor supply shocks would have a significant adverse impact on the major auto producers in Europe, with one-third of the decline in the value added of the car sector attributable to spillovers via supply chains within and across borders. Within borders, the pandemic-induced labor supply shocks in the services sector have a bigger adverse impact, reflecting their larger size and associated demand effects. Across borders, spillovers from the pandemic-induced labor supply shocks that originate in other European countries are larger than those that originate outside the region, though the latter are still sizable.

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I. Introduction

The auto sector is macro-critical in a number of European countries. It comprises a large share of manufacturing, employment, and exports. For instance, in Germany—the largest auto producer in Europe—the sector constitutes about 20 percent of manufacturing, 12 percent of employment, and 10 percent of goods exports (Figure 1). In some countries in Central, Eastern, and Southeastern Europe (CESEE), such as the Slovak Republic, it has an even larger footprint. The European auto industry is among the world's biggest motor vehicle producers and the largest private investor in research and development among all sectors in the European Union (EU).[1]

The auto sector also constitutes one of the main supply chains in Europe. In the early 1990s, as many countries in CESEE opened their borders to international trade and investment, their geographical proximity and cultural similarities, along with the large labor cost differential and increasing competition, led many German auto producers to shift large parts of their production to these locations, thus creating the German-Central European supply chain (IMF 2013). Since then, the sector has become increasingly complex with further fragmentation of production enabled by technological change and globalization. While bringing substantive efficiency gains, the fragmentation of production has also exposed the sector to disruptions in other sectors and countries, as exemplified during the COVID-19 pandemic.

The COVID-19 pandemic hit the auto sector hard. Containment measures ground car production to a halt in mid-2020. Subsequent lockdowns had a more limited impact on production, but in 2021 the sector was challenged by rising global demand for semiconductors, due to a boom in the production of household electronics, and disruptions in the supply of key inputs, because of the combined effects of the pandemic, weather events, and trade policies. As a result, auto producers were forced to scale back production of certain car models, and reduce the number of shifts of their workers.[2]

The goal of this paper is to assess the broader macroeconomic effects of the pandemic-induced lockdowns on the auto sector. It seeks to quantify the spillovers that affect and originate from the auto sector in the context of the pandemic and understand how those spillovers are transmitted via supply chain linkages. In particular, we address the following questions:

- How interconnected is the European auto industry—both in terms of supply and demand linkages?
- How important are labor supply shocks—such as the ones experienced during the initial phase of the pandemic—in the collapse in the auto sector?
- How much of the collapse can be explained by supply chain linkages—both domestic and foreign?

We first present a quantitative analysis of supply chain linkages in the auto sector. Here, we present two perspectives: (i) cross-sector: how supply chains in the auto sector compare with those in other sectors; and (ii) cross-country: how supply chains in the auto sector compare across countries. Our analysis suggests that the auto sector has one of the most complex and elaborate supply chains relative to other sectors. For instance, the length of supply chains in the auto sector—proxied by the number of production stages as in Fally (2012)—

[1] Research and development (R&D) spending by the auto sector in 2019 amounted to about 62 billion euros, more than twice the R&D spending of the pharmaceuticals and biotechnology sector, the second largest investor.

[2] See, for example, Čársky and Kiššová (2021).

is one of the longest. Domestic supply chains dominate, but foreign supply chains are still sizable, especially with other European countries. Regarding the demand side, the European auto sector is relatively downstream—i.e. closer to final demand. Foreign demand is important for the European auto sector, including demand in major economies outside the region, such as the United States and China.

Next, we deploy a multi-country multi-sector general equilibrium model to assess the impact of lockdowns and how those propagate across supply chains—both within and across borders. The multi-country and multi-sector setup allows us to assess the transmission of a sectoral shock to other sectors and countries, which we exploit to understand spillovers to and from the auto sector. The framework we use is also a structural setup with optimizing agents, which is crucial as it allows us to model lockdowns as labor supply shocks. Finally, the general equilibrium setup allows us to investigate spillovers of labor supply shocks not only via supply channels (production networks) but also demand channels (price/wage and related income effects). For a quantitative assessment we take the model to the data. There are two key steps. First, we calibrate the size of the labor supply shocks imposed in different sectors and countries. We do this by exploiting information on sectoral contact intensity and Oxford's stringency index.[3] Lockdown measures have evolved throughout the pandemic; we focus on the initial phase when lockdowns spanned most countries and sectors, which we use to analyze spillovers within and across borders. Second, we calibrate input-output linkages across sectors and countries using the OECD- Inter-Country Input-Output (ICIO) database. It is important to note that our analytical framework explores the role of the pandemic-induced labor supply shocks on the auto sector and does not seek to explain the overall contraction experienced by car manufacturers. The latter would require modeling demand shocks and comprehensive policy measures implemented during the pandemic.

Our main findings from the model-based analysis are as follows. Lockdowns of the kind put in place during the initial phase of the pandemic would have a sizable negative impact on the European auto sector: real value added would decline by about 30 percent relative to the steady state. Much of this impact is due to a direct impact from labor supply shocks in the auto sector itself. That said, spillovers from labor supply shocks in other sectors in the domestic economy and shocks in foreign countries are still sizable—these contribute to about one-third of the total impact. Thus, supply chain linkages are an important transmission mechanism. Finally, in terms of spillovers from the auto sector, we find that labor supply shocks that originate in the auto sector would have a small but non-trivial impact on the overall economy.

Our paper is related to a recent body of work that looks at how pandemic-induced lockdowns spill over via supply chains. Our analytical framework builds on Bonadio et al. (2020) who assess how labor supply shocks in different sectors and countries are transmitted via supply chains. Eppinger et al. (2020) focus on how lockdowns in China during the pandemic affect other countries via global value chains. Using a global value chain approach, Garcia, Kizior, and Simons (2020) analyze the potential impact of a hypothetical demand shock for cars across different countries and sectors. Klein et al. (2021) document that Central and Eastern European (CEE) countries almost fully stopped car production as lockdown measures in the initial phase of the pandemic disrupted supply chains. Relative to these papers, which focus on the aggregate economy-wide impact (e.g. Bonadio et al. 2020; Eppinger et al. 2020), we conduct a deeper sectoral analysis that allows us to distill the impact on the European auto sector. We also complement the literature that focuses on the car industry (e.g. Garcia, Kizior and Simons 2020; Banerjee and Zeman 2021; Klein et al. 2021), by modeling the

[3] Throughout the paper, we refer to the "pandemic-induced labor supply shocks" as shocks to labor supply as calibrated using the Oxford stringency index. The stringency index is, however, a dejure lockdown measure and does not fully capture the shocks to labor supply that are additionally due to voluntary social distancing.

effects of (labor) supply shocks, rather than demand shocks. The sectoral analysis also allows us to discern the relative importance of different sectors in propagating shocks. More broadly, there is a body of work that looks at the role of supply chains and production networks for spillovers and co-movement, such as, for instance, Huo et al. (2019), Acemoglu et al. (2012), and Baqaee and Farhi (2020). We add to this work stream by looking at the propagation of labor supply shocks. Finally, our paper—which deploys a general equilibrium framework—is related to recent work that shows that supply shocks can trigger aggregate demand effects (Guerrieri et al. 2020).

The rest of the paper is organized as follows. Section II presents stylized facts on the European auto sector focusing on its macroeconomic significance and recent dynamics. Section III discusses supply chains in the auto sector. Section IV lays out the analytical framework. Section V presents the main results from the model simulation, while Section VI examines their robustness. Section VII concludes.

II. Stylized Facts

A. Macroeconomic Significance of the Auto Sector in European Countries

In many European countries, the auto sector comprises a sizable share of the economy. In the EU, the auto industry generates a turnover of more than 7 percent of GDP, employs more than 6 percent of workers and accounts for an even larger share of exports.[4] The sector's relevance varies significantly across countries, with outsized presence, both in terms of value added, employment, and international trade, in Germany, Sweden, the Czech Republic, the Slovak Republic, Hungary, and Romania (Figures 1 and 2). Almost half of global exports of cars and car parts originate in Europe, with Germany in the lead.

Even though it is macro-critical, the European auto sector has lost significant market share over the past two decades. At the turn of the 20th century, Europe was the largest car producer in the world. However, while annual global auto production increased by more than 50 percent, from almost 60 million vehicles in 1999 to 90 million vehicles in 2019, Europe's production stalled at about 20 million vehicles per year. As a result, the European share of global auto production decreased from 36 percent in 1999 to 23 percent in 2019, with the majority of market share gains accruing to economies in Asia, and, to a smaller extent, Latin America (Figure 3).

[4] In this paper, EU refers to EU28 even though the UK is no longer part of the EU. Also, due to data availability, some results are based on data from the EU rather than for the full set of European countries. For more details on the EU auto sector, see: https://ec.europa.eu/growth/sectors/automotive_en.

Figure 1A. Gross Value Added of the Auto Industry

(Percent of gross value added of manufacturing, 2019)

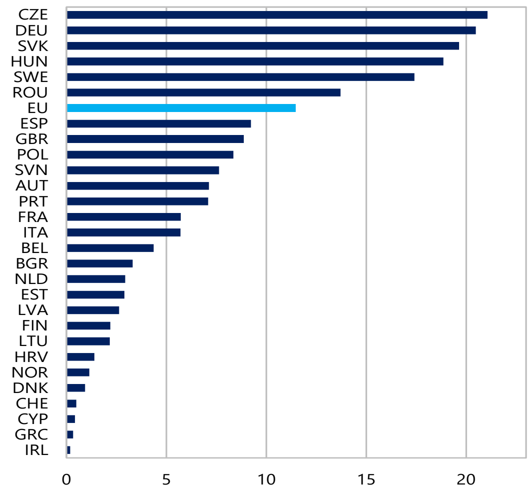
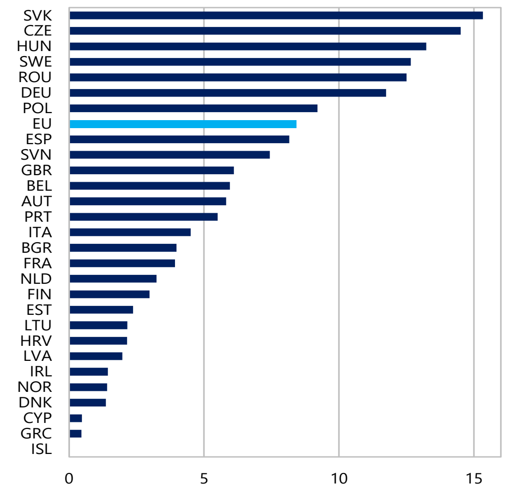


Figure 1B. Employment in the Auto Industry

(Percent of employment in manufacturing, 2019)

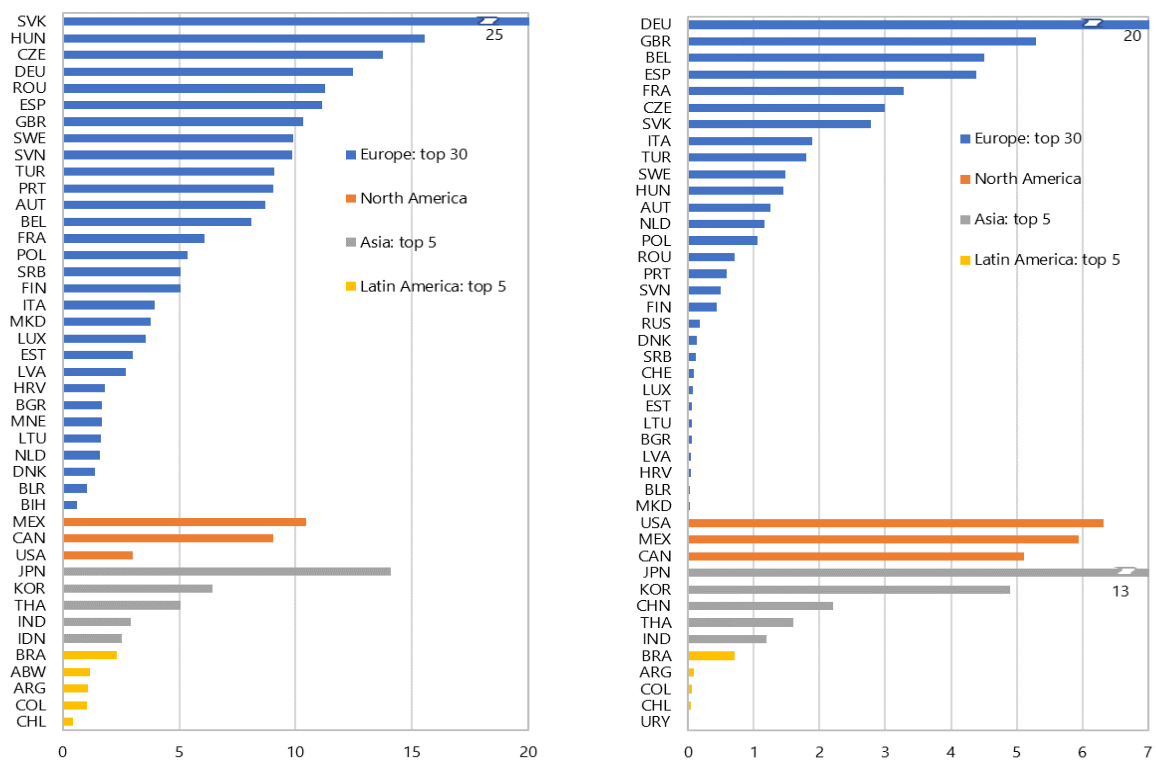


Sources: Eurostat; Haver Analytics; and IMF staff calculations.

Figure 2. Exports of Cars and Parts in Europe, 2018

A. Export of Cars and Car Parts, 2018

B. Export of Cars and Car Parts, 2018
(Percent of world car and car parts exports)



Sources: UN Comtrade; and IMF staff calculations.

Figure 3A. Global Vehicle Production by Region (Millions)

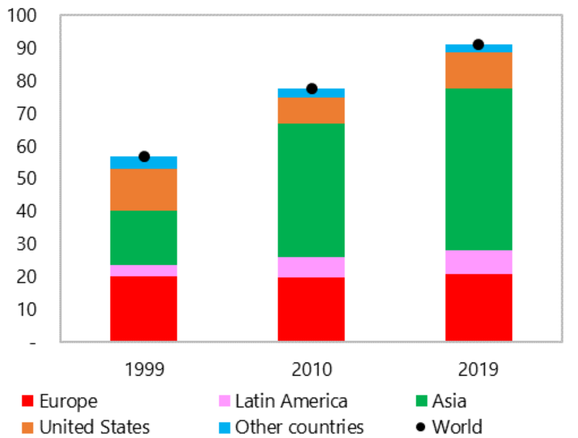
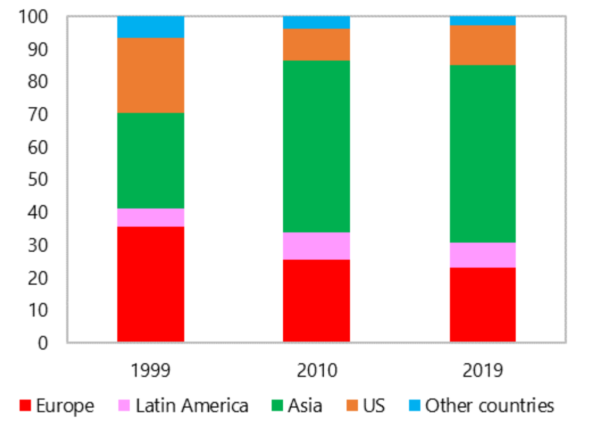


Figure 3B. Share of Global Vehicle Production by Region (Percent)



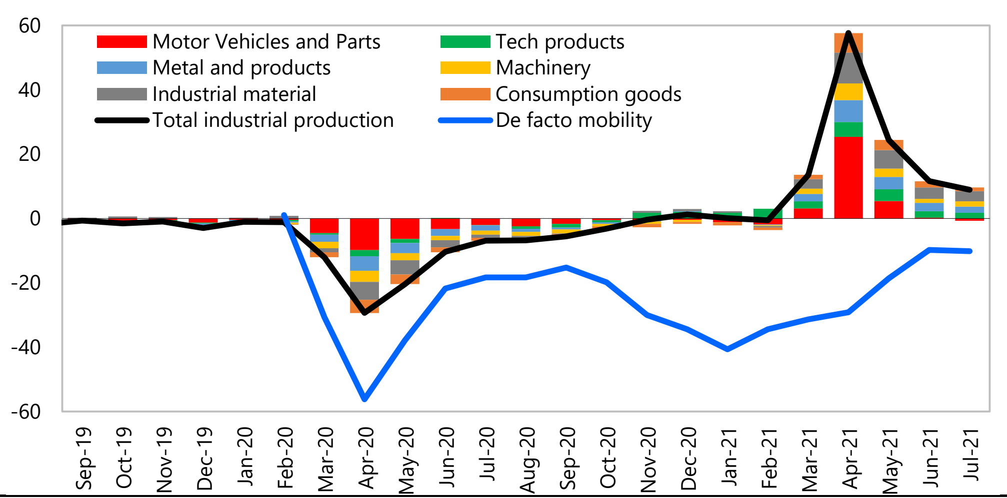
Source: OICA.

B. What Happened to the Auto industry during the COVID-19 Pandemic?

The pandemic greatly affected activity in Europe, and the auto industry was no exception. The initial lockdowns in 2020 hit manufacturing severely, and, given its large footprint, a considerable fraction of the collapse in industrial production was due to the auto sector (Figure 4). In 2020, vehicle production in Europe dropped by more than one-fifth: 4.5 million fewer cars were produced relative to 2019. During the first round of lockdowns in early 2020, nearly half of the jobs in the EU auto sector were affected.[5]

Figure 4A. EU: Contribution to the Change in Industrial Production, Manufacturing

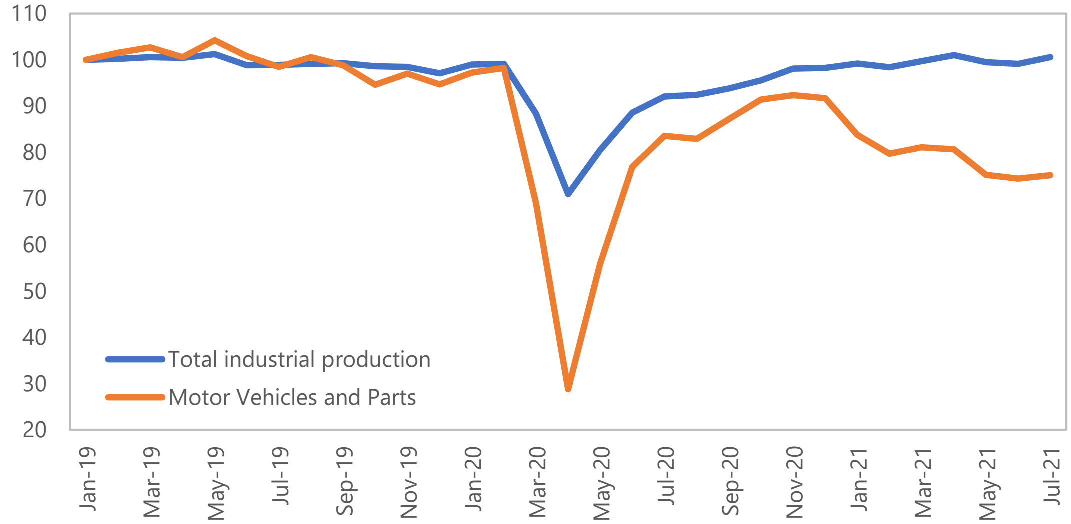
(Growth in percent; Contributions in percentage points, year-on-year)



[5] The European Automobile Manufacturers' Association estimates that the production loss in the European auto industry accounted for more than 100 billion euros or 0.75 percent of EU GDP (https://www.acea.be/news/article/coronavirus-covid-19).

Figure 4B. EU: Industrial Production and Production of Motor Vehicles and Parts

(Index, January 2019 = 100)

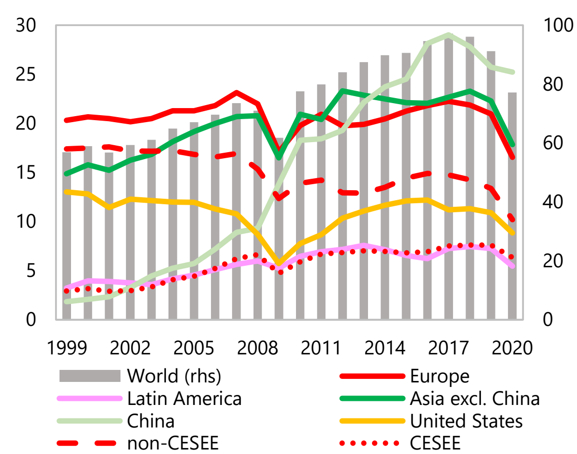


Sources: Eurostat, Google Mobility Report, and IMF staff calculations.
Note: In Figure 4A, the following subgroups were aggregated: Energy = Coke and Petroleum; Motor Vehicles = Vehicles; Tech products = Computers; Metal and products = Metals; Machinery = Machinery and equipment; Industrial material = rubber + chemicals and pharmaceuticals + other; Consumption goods = food + textiles + wood.

The dip in car production in 2020 deepened the gradual decline in global vehicle production, which had started before the pandemic. Vehicle production in the world reached a peak in 2017 with 97 million vehicles produced. In 2018-19, production dropped by around 6 percent due to tighter emission standards and weakening global demand (IMF 2019a; IMF 2019b), and, with the pandemic in 2020, it declined by an additional 15 percent to 77 million vehicles (Figure 5). Similar to the 2009 crisis, a large fraction of the decline during the COVID-19 crisis was contributed by Europe, while production in China remained relatively resilient (Figure 6).[6] Within Europe, the growth rate of car production has been negative in non-CESEE European countries since 2017 and the contraction in production was deeper than that in CESEE during the pandemic (Figure 7).

Figure 5. Vehicle Production: 1999-2020

(Millions)

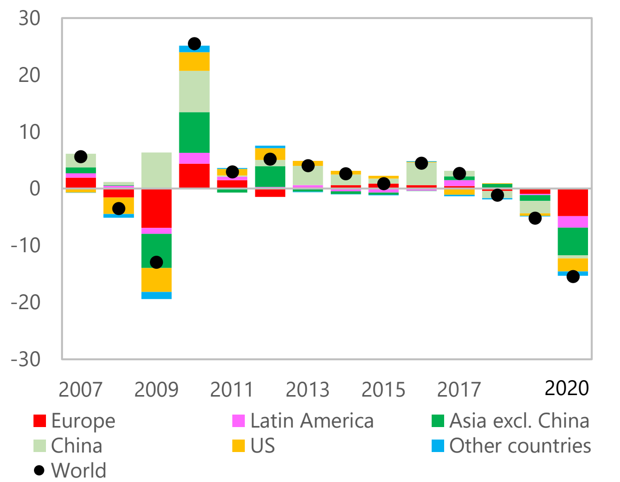


Source: OICA.

[6] In contrast to other regions, in China producers increased their production during the global financial crisis (GFC), which could be explained by rising demand in China and the move of production to China from countries experiencing a severe recession. The contribution of China to global auto production growth continued to be sizable for several years following the GFC until 2018, when US-China trade tensions hit the Chinese auto industry.

Figure 6. Contribution to Change in Global Vehicle Production

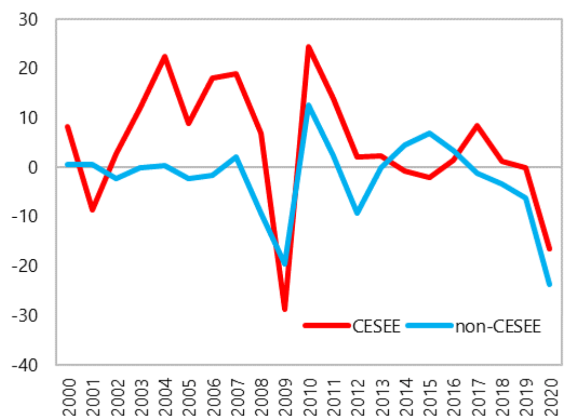
(Growth in percent; Contributions in percentage points)



Sources: OICA and IMF staff calculations.

Figure 7. Growth in European Vehicle Production

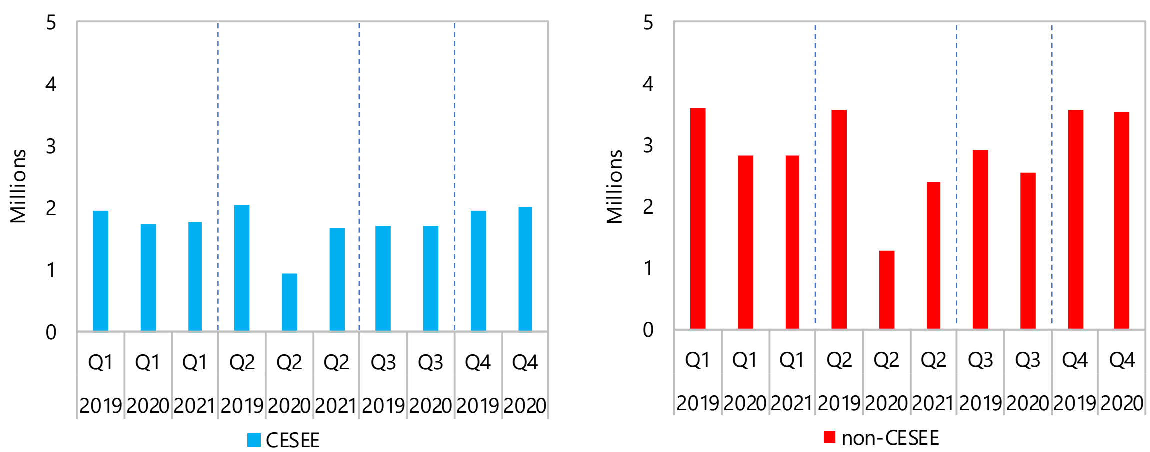
(percent)



Sources: OICA and IMF staff calculations.

Figure 8. Quarterly Vehicle Production in Europe

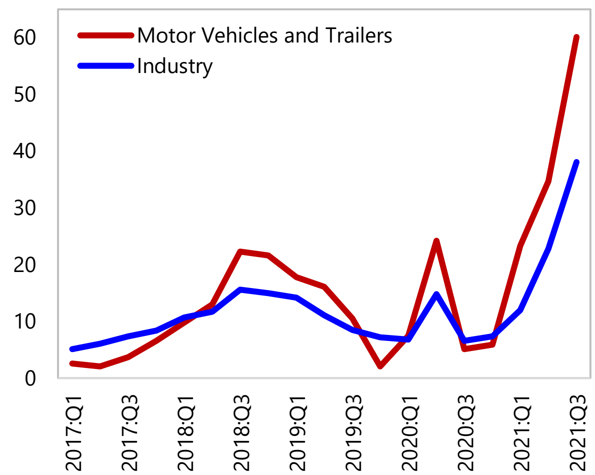
(millions)



Source: OICA.

The auto sector has shown adaptability during the course of the pandemic, but supply chain disruptions have increasingly weighed on the sector in 2021. Although total production in 2020 remained well below the 2019 level, auto production rebounded in 2020:Q3, after a 70 percent year-over-year decline in 2020:Q2 and that recovery continued throughout the second wave of infections in Europe. The lack of mandated lockdowns and the measures adopted by car manufacturers helped maintain production, even as infections were rising.[7] With these efforts, production in 2020:Q4 and 2021:Q1 reached pre-pandemic (2019:Q4-2020:Q1) levels (Figure 8). But disruptions in the complicated supply chains of the auto industry became the main factor behind the subdued performance of the sector later on. Uneven COVID-19 infection rates and restrictions around the world, spikes in the demand for key components from other sectors and longer input shipping times have led to disruptions in car production across Europe. A notable example is the shortage of semiconductor components for autos in 2021 as semiconductor supplies were diverted to consumer electronics, such as gaming systems, home electronics, and personal computers, whose demand skyrocketed. Such supply chain disruptions intensified through 2021, constraining car production (Figure 9).

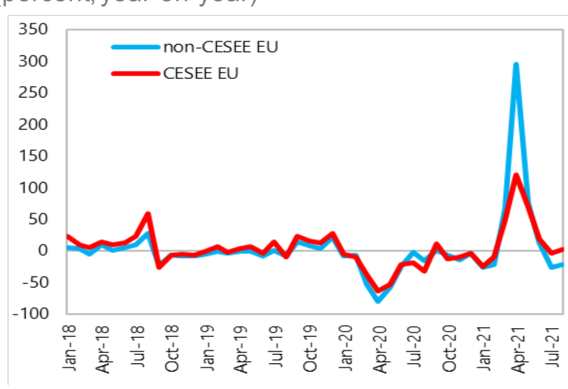
Figure 9. Euro Area: Equipment as a factor Limiting Production
(percent)



Source: Haver Analytics.

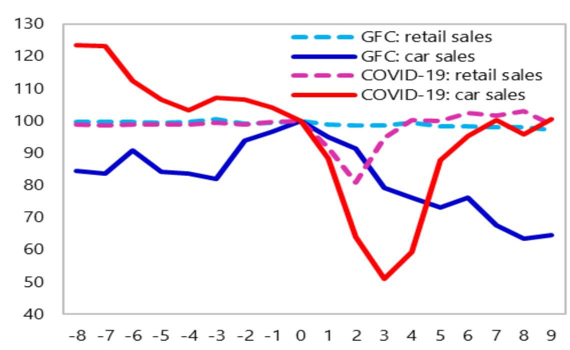
In addition to reduced production, demand for cars also fell sharply at the beginning of the pandemic, but rebounded afterwards. In April 2020, new passenger car sales in Europe were around 80 percent lower than the previous year's levels, with even deeper declines in some advanced European countries, such as Ireland, Italy, Spain, and the UK (Figure 10). The decline in sales was much deeper and faster during the COVID-19 pandemic than during the global financial crisis (GFC), in part, reflecting the impact of lockdown measures and closures of car dealerships (Figure 11). However, car sales recovered much faster during the

Figure 10. EU: Car Sales
(percent, year-on-year)



Sources: Eurostat and IMF staff calculations.
Note: CESEE-EU countries include Czech Republic, Estonia, Latvia, Lithuania, Slovak Republic, Slovenia, and Poland. Non-CESEE EU are the EU-15 countries which include the UK.

Figure 11. EU: Cars and Retail Sales
(Index)



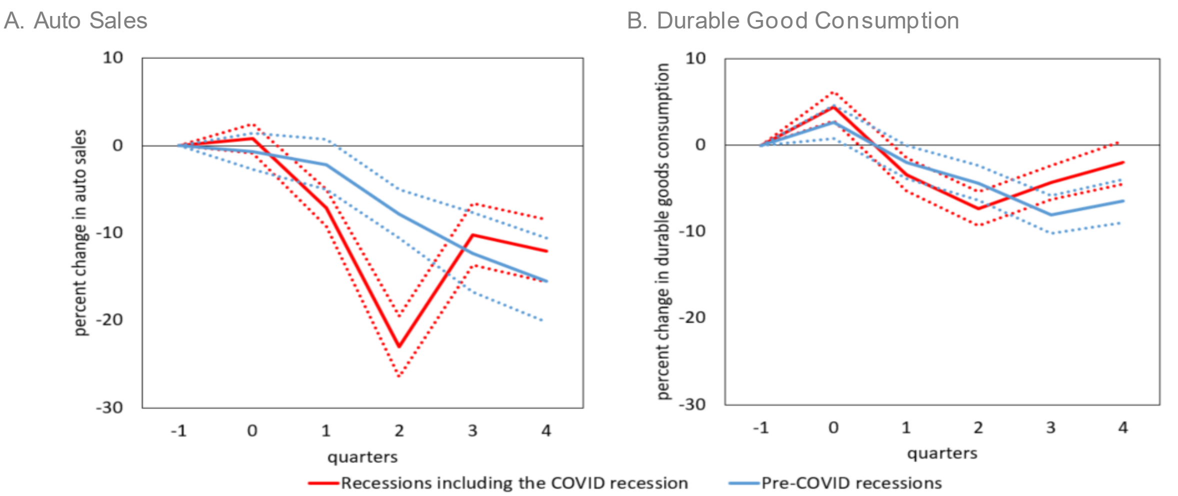
Sources: ACEA; Eurostat; and IMF staff calculations.
Note: All series are rescaled to equal 100 at time 0. Time 0 indicates the start of the decline in car registration around two recession episodes, namely May 2008 for the GFC and February 2020 for COVID-19. EU figures include the United Kingdom.

[7] For instance, in the Slovak Republic, there are anecdotal reports that car factories hired extra workers to substitute for the workers getting sick or being quarantined. In addition, the factories did a lot their own testing of workers.

pandemic. By the second half of 2020, car sales had reached pre-pandemic levels, in contrast to their continued decline in the aftermath of the GFC.

The dynamics of car sales during the pandemic differs from the experience of the auto industry following past recessions. To assess the (short-term) impact of recessions on the auto industry, we analyze the dynamics of car sales following 87 recessions in an unbalanced panel from 26 countries over 24 years.[8] We trace sales of cars and durable goods—for comparison—after the onset of a recession, distinguishing between the average experience for all 87 recessions in our sample, and the 61 recessions that occurred prior to the pandemic. Our analysis establishes several stylized facts. First, after the onset of a typical recession prior to 2020, car sales and sales of consumer durables generally tend to remain depressed for several quarters. Demand for cars appears to be particularly sensitive to downturns, with deeper post-recession dips in sales than durable goods consumption. Second, the COVID-19 associated downturn stands out. The decline in car sales a year into a typical recession—before the pandemic—was around 10-15 percent. However, the decline in car sales is much deeper, at around 25 percent after 2 quarters, when we include recessions associated with the pandemic, with a strong rebound visible the third quarter into the recession (Figure 12A). Interestingly, this pattern applies to car sales only: the demand for durable goods during the COVID-19 recession was not too different compared to previous recessions (Figure 12B).

Figure 12. EU: Car Sales and Durable Goods Consumption in Europe Following Recessions
(percent)



Sources: ECB and IMF staff calculations.
Notes: Quarter 0 indicates the identified peak of the business cycle. For the COVID-19 episode, the identified peak is 2019:Q4.

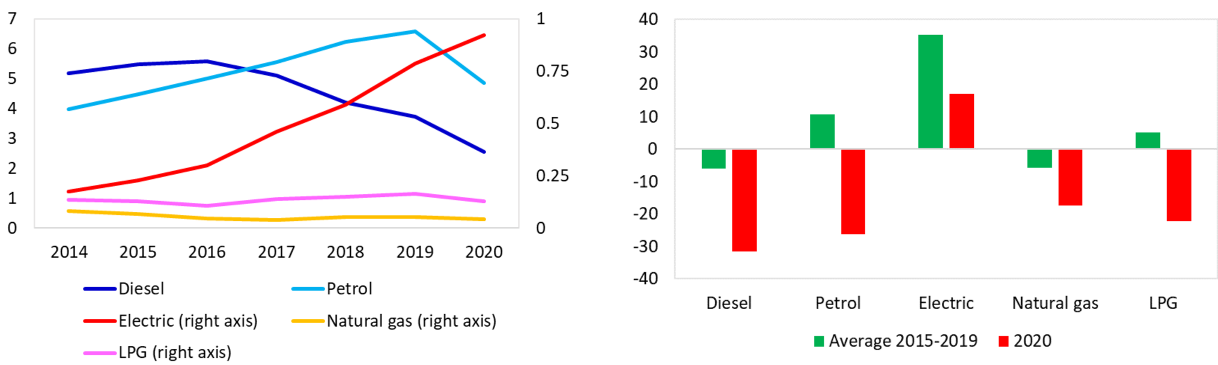
[8] We identify the start of recessions using the Bry and Boschan (1971) business cycle algorithm on real GDP and use the local projection method (Jordà 2005) to examine the dynamics of car and durable sales after the start of recessions.

C. Mega Trends

From changing consumer behaviors and preferences for digitalization and automation, there are several trends that could disrupt the auto sector. Transformative changes in the sector that started earlier have gained traction and pace following the pandemic. In light of rapid technological developments, changing consumer preferences and supportive policies, we will not wait long before we see only electric vehicles on roads and even have fully autonomous vehicles controlled by artificial intelligence. The shift in demand away from diesel and petrol to electric vehicles is clear. To mitigate air pollution and climate change, several countries in Europe have banned the sale of new diesel vehicles and implemented generous tax incentives for the use of electric vehicles, which have supported electric cars sales (Figure 13).[9] With the pandemic, this trend has gained pace: sales of electric cars continued to grow in 2020, in contrast to the decline in the sales of internal combustion engine cars. As a result, the share of electric vehicle sales in Europe almost tripled in 2020 relative to the pre-pandemic shares.

Figure 13. Car Sales by Fuel Type: Germany, France, UK, Italy, Spain (Top 5 countries)

Car sales (millions) Annual car sales growth (percent)



Source: Bloomberg.

III. Supply Chains in the European Auto Sector

The European auto sector experienced dramatic growth in supply chain specialization in recent decades. Technological advances and declines in trade costs have led to the increasing fragmentation of production in the European auto sector, with different stages of production often taking place in different countries. While this has led to significant gains in efficiency and productivity, it has also made production processes more vulnerable to supply chain disruption events.[10] This vulnerability can be more prominent when intermediate inputs are very specific along the supply chains and cannot be easily provided by other suppliers,

[9] The European Commission's climate policy package, proposed in July 2021, includes new regulations for the transport sector. Notably, all new vehicle sales are required to be emission free by 2035. To this end, the Recovery and Resilience Facility (RRF), the centerpiece of the Next Generation EU plan, requires at least 37 percent of recipient countries' investments financed by RRF grants to be directed towards the green transition, including projects such as extending the network of charging points for electric vehicles.

[10] By diversifying the sources of demand and supply across countries, openness to international trade, *on average*, could result in reduced volatility when country-specific shocks are important (Caselli et al. 2020). This is, however, less likely to be relevant in a pandemic when shocks are more global in nature.

as in the case of the auto sector (World Bank 2019). Thus, understanding supply chain linkages is key to understanding cross-country and cross-sectoral spillovers.

We present a systematic analysis of supply chain linkages in the European auto sector. Based on the direction of transmission, we do so from two angles. First, we discuss the supply side to inform how disruptions from upstream suppliers (e.g., machinery) would affect downstream producers (e.g., auto). Second, we analyze the extent to which the European auto sector is exposed to changes in final demand. The analysis is based on the OECD ICIO database (2018 edition), which contains sectoral production, consumption, value-added, and trade information for 64 countries (34 of which are in Europe) and 36 sectors, with 2015 as the latest available year.

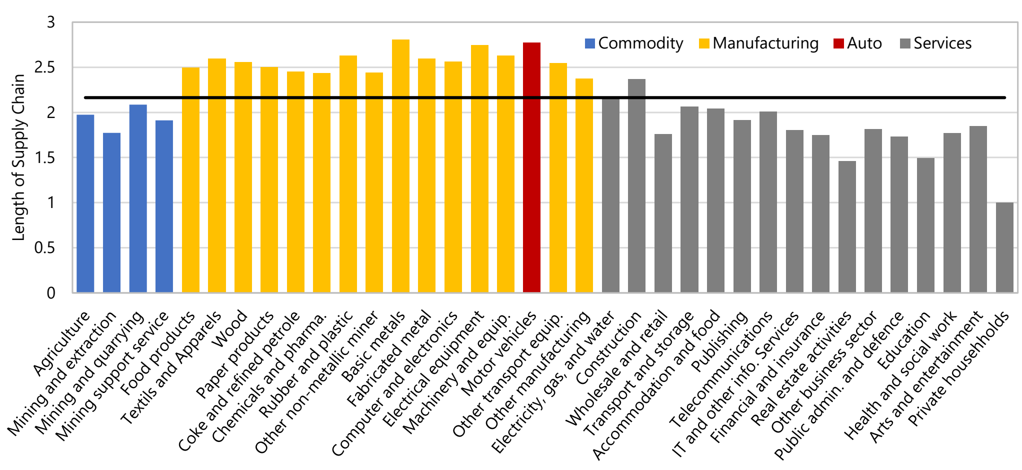
A. Supply Side

Two features of the European auto supply chain make the auto sector particularly exposed to disruptions in the context of a pandemic.

Auto manufacturing has one of the most complex and elaborate supply chains relative to other sectors. Figure 14 shows a well-established measure of supply chain length (Fally 2012), which captures how many production stages a particular sector needs to go through in order to produce the sectoral goods—a higher index reflects a longer supply chain. [11] The auto sector (along with the production of basic metals) has the longest supply chain of all sectors in the economy. This is intuitive: the production of a car requires many components (intermediate inputs) that are produced by other sectors or its own—such as steering wheels, engines, car windows. On the other hand, the services sector mainly uses labor or human capital and relies less on intermediate inputs (Figure A3).

Figure 14. Length of Supply Chains

(index)



Sources: OECD ICIO and IMF staff calculations.

Note: Higher index implies longer supply chains.

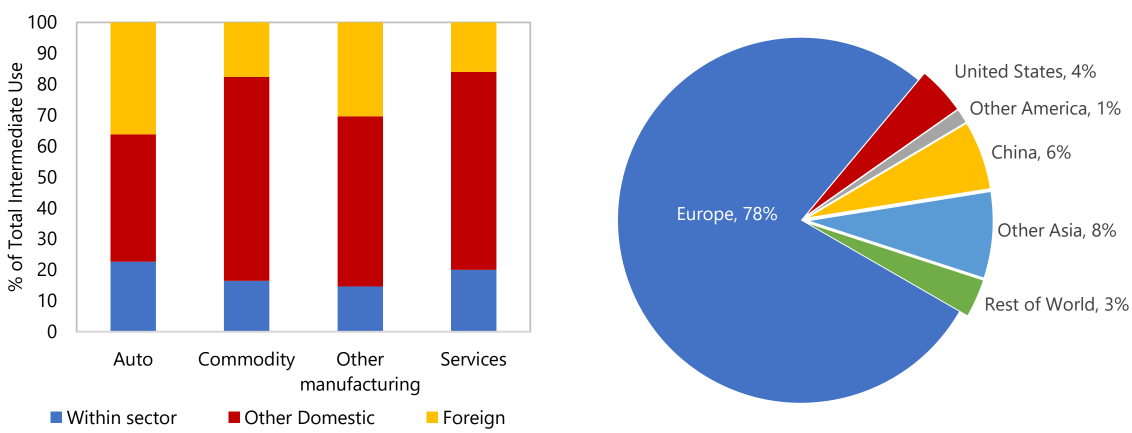
[11] Supply chain length and upstreamness index (in the subsequent discussion) are calculated for all countries in the OECD ICIO database, thus they speak to the auto sector in general. We also present alternative measures—intermediate input usage, value-added exports—that are Europe-specific.

Although most intermediate inputs come from domestic sources, car production relies to a greater extent on foreign suppliers, compared to other sectors. Figure 15A illustrates another measure of global supply chain linkage: the direct dependency on intermediate inputs by sourcing locations, namely usage of intermediate inputs produced by (i) the sector itself, (ii) other sectors in the domestic economy, and (iii) foreign countries. [12] For the average auto sector in Europe, more than 60 percent of intermediate inputs are sourced from within the country. Foreign inputs account for a smaller share of total inputs, at around 35 percent. In the context of a pandemic—where both domestic and foreign supply chains are disrupted—this implies that domestic supply chain disruptions (e.g. workers being unable to supply labor due to lockdowns) can matter more than disruptions in foreign supply chains. Relative to other sectors though, the share of foreign inputs in the auto sector is larger. Figure 15B presents a geographical breakdown of the foreign component for the auto sector. Close to 80 percent of all foreign intermediate usage by the European auto sector is accounted by other European countries. [13] Taken together, disruptions in foreign supply chains, especially in other European countries, would have larger impact on the auto sector relative to other sectors.

Figure 15. Intermediate Input Usage

A. Decomposition of Intermediate Use in Europe (percent)

B. Decomposition of Foreign Intermediate in European Auto Sector (percent)



Sources: OECD ICIO and IMF staff calculations.

Note: Sectoral statistics for Europe are computed as the weighted average of country-specific figures using value-added shares as weights.

[12] The aggregate for the auto sector in Europe is computed as the weighted average of country-specific figures using value-added shares as weights (i.e. value-added of country-specific auto sectors in European total auto value-added). The same approach is used to compute the European aggregate for other sectors.

[13] We also analyze other supply chain indicators, such as GVC backward participation. These measures show broadly similar patterns.

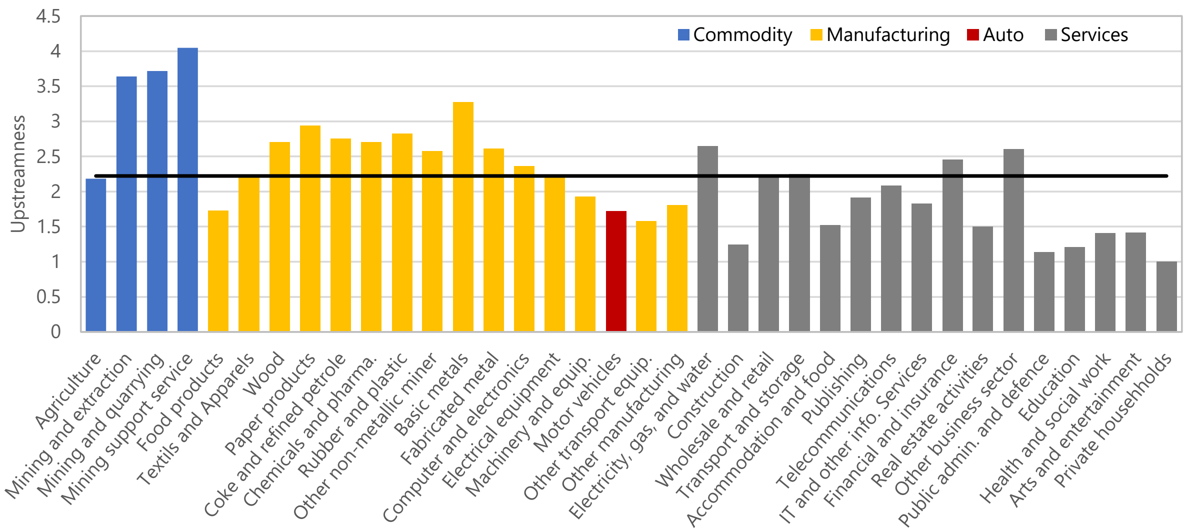
B. Demand Side

The demand structure of the European auto sector exposes the sector to shocks to final demand, both within and outside of Europe.

The auto sector is relatively downstream—in other words, closer to final demand. Figure 16 shows the sectoral upstreamness measure developed by Antràs et al. (2012), which captures how far a specific sector is from the final end usage—a lower index implies the sector is relatively downstream, in other words, closer to final demand. Relative to other sectors, the lower index for the auto sector implies that it is quite sensitive to final demand shocks.

Figure 16. Upstreamness Indicator

(index)



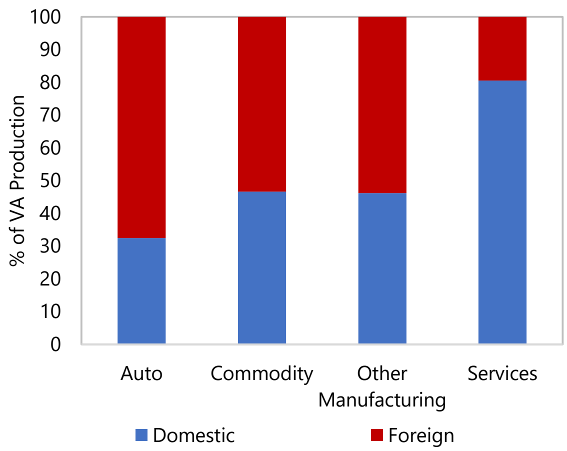
Sources: OECD ICIO and IMF staff calculations.
Note: Lower index implies sector is less upstream, or closer to final demand.

Foreign demand is especially important for the auto sector in European countries, including demand in major economies outside the region. Focusing on the geographical distribution of the final absorption of the value added in European countries—i.e. the destinations of value-added exports, Figure 17A shows that close to 65 percent of value-added exports of the European auto sector are absorbed by foreign countries. This is a much sizable share relative to other sectors. Furthermore, while most of the European auto sector's value-added exports are finally consumed within Europe, final demand in major economies outside of the region, in particular the United States, China and other Asian economies, are significant (Figure 17B). All in all, this implies that the European auto sector would be adversely affected by declining foreign demand, as one would expect during a global recession.

Figure 17. Destinations of Value-Added Exports

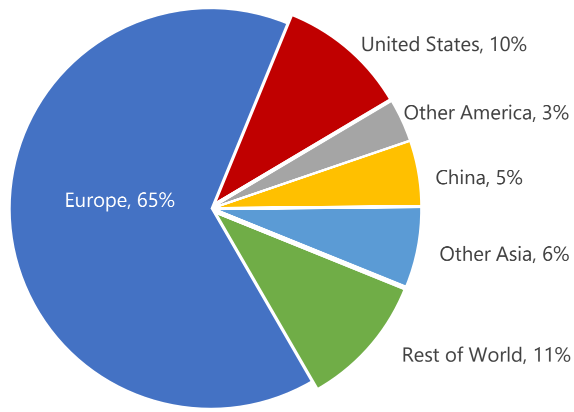
A. Decomposition of VA Production in Europe: By Destination

(percent)



B. Decomposition of VA Exports for European Auto Sector

(percent)



Sources: OECD ICIO and IMF staff calculations.

IV. Labor Supply Shocks and the Auto Sector: Analytical framework

The analytical framework we deploy is a multi-country multi-sector general equilibrium model that explicitly features supply chain linkages and labor supply shocks. Our framework is based on Bonadio et al. (2020), but we model sector-specific shocks, which is crucial for a deeper sectoral analysis. There are three aspects of this framework that are relevant for our study. First, by explicitly modeling supply chain linkages across sectors and countries, the framework allows us to assess the transmission of sectoral shocks within the domestic economy and across borders. In our application, we analyze how shocks originating in other sectors and countries affect the auto sector, and how shocks originating in the auto sector affect other sectors and countries. Second, the structural framework with optimizing agents allows us to model labor supply shocks and presents a mechanism to relate to lockdowns during the pandemic. Third, the general equilibrium framework allows us to investigate spillovers of labor supply shocks via both supply and demand channels. The supply channel is rather straightforward if one thinks of a production network and is already captured, in part, by the multi-sector multi-country production linkage. For instance, labor as a factor input in the production of upstream car parts can affect downstream car production. The transmission via the demand side is less trivial, as it occurs via price and wage effects that eventually determine demand in both final and intermediate usage in the model—this is where the general equilibrium framework we deploy is particularly relevant.

A. Model Setup

The model setup is as follows. There are N countries (indexed by n and m), and J sectors (indexed by j and i) in each country. Each country n is populated by a representative household. The household consumes the final good available in country n , F_n , and supplies labor and capital to firms. International trade is subject to iceberg trade costs τ_{mnj} to ship good j from country m to country n.

Households. There is a continuum of workers in a representative household who gain utility from the common consumption bundle and supply labor for a wage. The household's utility maximization problem is:

$$\max_{F_n,\{H_{nj}\}} U(F_n - \frac{\psi}{1+\psi} \sum_j \xi_{nj} H_{nj}^{1+\frac{1}{\psi}})$$

subject to:

$$P_n F_n \equiv \sum_{m,j} P_{mnj} F_{mnj} = \sum_j W_{nj} H_{nj} + \sum_j R_{nj} K_{nj}$$

On the supply side, H_{nj} is the total labor hours supplied to sector j, and K_{nj} is the amount of installed capital. For tractability, we assume capital to be fixed. [14]

Each hour of labor supplied collects a sector-specific wage W_{nj}, and capital is rented at the sector-specific rental rate R_{nj}. The parameter ψ denotes the Frisch elasticity that governs the responsiveness of labor supply, and ξ_{nj} is the preference shock on the labor supply of sector j. This functional form of the utility function follows Greenwood, Hercowitz, and Huffman (1988) and yields a simple isoelastic labor supply curve that only depends on the real wage:

$$H_{nj} = \left(\frac{W_{nj}}{\xi_{nj} P_n}\right)^{\psi} \qquad (1)$$

As the above expression shows, an increase in ξ_{nj} is interpreted as an adverse shock that would result in a reduction in labor supply. A key difference from Bonadio et al. (2020) is that the labor supply shock in our formulation is country-sector specific—this is convenient since we want to explore the transmission of shocks that originate in specific sectors and countries.

On the demand side, F_n denotes the consumption of final goods with corresponding aggregate consumer price index P_n. The term F_{mnj} denotes the final use in country n of sector j goods coming from country m and P_{mnj} is the corresponding price. The final consumption F_n is a Cobb-Douglas aggregate across sectoral final composites, where each sectoral final composite aggregates up country-specific absorptions of this specific final goods:

[14] In this paper, we focus on the very short-term/immediate impact of labor supply shocks, which justifies the assumption of fixed capital. The analysis also abstracts from job retention schemes that offer income protection to households (which can affect their labor supply and consumption decisions) and hiring subsidies to businesses (which can affect firms' labor demand).

$$F_n = \prod_{j=1}^{J} (F_{nj})^{\omega_{nj}}, F_{nj} = \left[\sum_m \vartheta_{mnj}^{\frac{1}{\rho}} F_{mnj}^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}} \quad (2)$$

The corresponding price indices can be also expressed by the following CES aggregation:

$$P_n = \prod_{j=1}^{J} \left(\frac{P_{nj}}{\omega_{nj}} \right)^{\omega_{nj}}, P_{nj} = \left[\sum_m \vartheta_{mnj} P_{mnj}^{1-\rho} \right]^{\frac{1}{1-\rho}} \quad (3)$$

The final expenditure share of a particular good from country m and sector j that is imported by country n is given by:

$$\frac{P_{mnj} F_{mnj}}{\sum_{k,l} P_{knl} F_{knl}} \equiv \pi_{mnj}^{f} = \omega_{nj} \frac{\vartheta_{mnj} P_{mnj}^{1-\rho}}{\sum_k \vartheta_{knj} P_{knj}^{1-\rho}} = \omega_{nj} \pi_{mnj}^{c} \quad (4)$$

Firms. A representative firm in country n and sector j operates with a Cobb-Douglas production function:

$$Y_{nj} = Z_{nj} \left(K_{nj}^{\alpha_j} H_{nj}^{1-\alpha_j} \right)^{\eta_j} X_{nj}^{1-\eta_j} \quad (5)$$

where Z_{nj} denotes TFP, K_{nj} and H_{nj} are the corresponding capital and labor supply from the household, and X_{nj} is the intermediate input usage that aggregates inputs from all potential countries and sectors:

$$X_{nj} = \left(\sum_i \sum_m \mu_{mi,nj}^{\frac{1}{\varepsilon}} X_{mi,nj}^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}} \quad (6)$$

The term $X_{mi,nj}$ denotes the usage of inputs coming from sector i in country m in production of sector j in country n, and $\mu_{mi,nj}$ is the intermediate taste shifter. [15] As in the final good price index, the price index of this intermediate input bundle is derived as:

$$P_{nj}^{x} = \left(\sum_i \sum_m \mu_{mi,nj} P_{mi,nj}^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}} \quad (7)$$

where $P_{mi,nj}$ denotes the price paid in country n, sector j for inputs from country m, sector i.
Let P_{nj} denote the price of output produced by sector j in country n. No arbitrage in shipping implies:

$$P_{mi,nj} = P_{mni} = \tau_{mni} P_{mi} \quad (8)$$

Cost minimization implies the following optimality conditions:

$$R_{nj} K_{nj} = \alpha_j \eta_j P_{nj} Y_{nj} \quad (9)$$

[15] In our application, we keep the intermediate taste shifter fixed and exogenous.

$$W_{nj}H_{nj} = (1-\alpha_j)\eta_j P_{nj}Y_{nj} \tag{10}$$

$$P_{mi,nj}X_{mi,nj} = \pi^x_{mi,nj}(1-\eta_j)P_{nj}Y_{nj} \tag{11}$$

where $\pi^x_{mi,nj}$ is the share of intermediates from country m, sector i in total intermediate spending by country n, sector j, given by:

$$\frac{P_{mi,nj}X_{mi,nj}}{\sum_{k,l} P_{ki,nl}X_{ki,nl}} \equiv \pi^x_{mi,nj} = \frac{\mu_{mi,nj}(\tau_{mni}P_{mi})^{1-\varepsilon}}{\sum_{k,l}\mu_{kl,nj}(\tau_{knl}P_{kl})^{1-\varepsilon}} \tag{12}$$

Equilibrium conditions. An equilibrium is a set of goods and factor prices $\{P_{nj}, W_{nj}, R_{nj}\}$, factor allocations $\{K_{nj}, H_{nj}\}$, and goods allocation $\{Y_{nj}\}, \{F_{mnj}, X_{mi,nj}\}$ for all countries and sectors such that given labor supply shocks $\{\xi_{nj}\}$:

(i) households maximize utility by satisfying (1)-(4),
(ii) firms maximize profits through (5)-(12),
(iii) all markets clear.

More specifically, market clearing conditions for sectoral goods satisfy:

$$P_{nj}Y_{nj} = \underbrace{\sum_m \sum_i \eta_i P_{mi} Y_{mi}\omega_{mj}\pi^c_{nmj}}_{final\ use} + \underbrace{\sum_m \sum_i (1-\eta_i)P_{mi}\, Y_{mi}\pi^x_{nj,mi}}_{\text{intermediate use}} \tag{13}$$

Labor market clearing condition implies that labor supply meets the corresponding labor demand from representative firms in each country and sector:

$$H_{nj} = \left(\frac{W_{nj}}{\xi_{nj}P_n}\right)^{\psi} = \frac{(1-\alpha_j)\eta_j P_{nj}Y_{nj}}{W_{nj}} \tag{14}$$

B. Model Solution

We assess the impact of the labor supply shocks in terms of real value added, which is standard in this class of models. For this, we first derive the impact of the shocks on gross output and labor using a first-order approximation solution as in Huo et al. (2019) and Bonadio et al. (2020). [16] Using vector notation, the equilibrium response of gross output $ln\,\boldsymbol{Y}$ to labor supply shocks $ln\,\boldsymbol{\xi}$, where "$ln(\,)$" denotes log-deviation from the steady state, is given by:

$$\ln \boldsymbol{Y} = -A_z \frac{\psi}{\psi+1}\boldsymbol{\eta}(I-\boldsymbol{\alpha})\ln\boldsymbol{\xi} \tag{15}$$

where

[16] Detailed derivations are presented in Appendix B.

$$A_z = \left[I - \underbrace{\frac{\psi}{\psi+1}\boldsymbol{\eta}(I - \boldsymbol{\alpha})\big(I + (I - \boldsymbol{\Pi}^f \otimes \mathbf{1})A_p\big)}_{Real\ Wage\ Adjustment} - \underbrace{(I - \boldsymbol{\eta})(I + (I - \boldsymbol{\Pi}^x)\ A_p)}_{Intermediate\ Input\ Adjustment} \right]^{-1} \tag{16}$$

The matrix $A_p = \frac{ln\,\boldsymbol{P}}{ln\,\boldsymbol{Y}}$ is the equilibrium influence matrix of sectoral prices to sectoral outputs, which governs the general equilibrium effects through good markets clearing. The matrices Π^f and Π^x are matrices of final consumption and intermediate expenditure shares.

The equilibrium response of hours $ln\boldsymbol{H}$ is derived as:

$$ln\ \boldsymbol{H} = -\frac{\psi}{\psi+1}\boldsymbol{\eta}\left\{\widehat{\boldsymbol{\eta}}^{-1} + \left[\frac{\psi}{\psi+1}(I - \boldsymbol{\alpha}) + \frac{\psi}{\psi+1}(I - \boldsymbol{\alpha})(I - \boldsymbol{\Pi}^f \otimes \mathbf{1})A_p\right]A_z\right\}\ln \boldsymbol{\xi} \tag{17}$$

where $\widehat{\boldsymbol{\eta}}$ is a square matrix whose diagonal elements represent the vector $\boldsymbol{\eta}$ and 0 elsewhere.
Having derived the equilibrium responses of gross output and labor, the equilibrium response of (real) value-added $ln\boldsymbol{V}$ is derived as:

$$\ln \boldsymbol{V} = (I - \boldsymbol{\alpha})\ln \boldsymbol{H} = V_\xi \ln \boldsymbol{\xi} \tag{18}$$

where

$$V_\xi = -\frac{\psi}{\psi+1}\boldsymbol{\eta}(I - \boldsymbol{\alpha})\left\{\underbrace{\widehat{\boldsymbol{\eta}}^{-1}}_{Direct} + \underbrace{\left[\frac{\psi}{\psi+1}(I - \boldsymbol{\alpha}) + \frac{\psi}{\psi+1}(I - \boldsymbol{\alpha})(I - \boldsymbol{\Pi}^f \otimes \mathbf{1})A_p\right]A_z}_{Indirect\ (GE)}\right\} \tag{19}$$

As equations (17-19) illustrate, the impact of labor supply shocks on value added is via endogenous changes in hours and intermediate inputs (capital is fixed in our framework). The linearized model solution has the advantage that we can perform an additive decomposition of the impact on value added due to various combinations of sector-specific labor supply shocks. We exploit this feature to evaluate how shocks in other sectors/countries affect the auto sector and vice versa.

C. Transmission Channels

The overall transmission of labor supply shocks can be broadly decomposed into two effects: the within-sector and the cross-sector effects. The within-sector effect refers to the direct impact of the sectoral labor supply shock ξ_{nj} to its own real value-added through wage and hours worked adjustments, holding all other prices constant. On the other hand, the cross-sector effect includes supply chain propagations through price variations of both intermediate inputs (upstream and downstream) and consumption price indices (demand from final use). The cross-sector effect can be within the domestic economy and across borders.

We provide some intuition behind the decomposition, which is reflected in equation (19). Regarding the within-sector effect, an adverse labor supply shock in the German auto sector, for example, would reduce the hours supplied in that sector for a given real wage, reducing production and value added in that sector. The relative magnitude of this effect is primarily determined by the Frisch elasticity ψ. The cross-sector effect can be summarized in terms of the following two channels:

(i) **Supply chain channel.** As an input to the auto sector, a hit to the German machinery sector would adversely affect production in the German auto sector (domestic spillover). Similarly, a hit to the Slovak machinery sector would impact the German auto sector (foreign spillover).

(ii) **Demand channel.** An adverse labor supply shock, *ceteris paribus*, would work to increase real wages (due to the labor market clearing condition). At the same time, a reduction in sectoral production due to the shock would imply an increase in the aggregate price index (following the goods market clearing condition)—this would push down real wages. In our implementation, it turns out that the net impact is an increase in real wages. But as equilibrium labor supply is reduced as the result of the adverse shock, the overall real labor income is reduced, reducing overall demand. Thus, a labor supply shock to the German service sector would weigh on the German auto sector via the demand channel. [17] As a corollary, a labor supply shock in the German auto sector would reduce demand for other sectors.

D. Calibration

Labor supply shock. Following Bonadio et al. (2020), we calibrate the size of the labor supply shock using data from two sources. The first one is a "work from home" measure by Dingel and Neiman (2020), WfH_j, which reflects the extent to which the production of a specific sector j could be performed remotely. The index differs across sectors—for instance, remote work is more feasible in sectors such as IT while more difficult in contact intensive sectors, such as hospitality (Figure A1). We maintain the simplifying assumption that a sector-specific index applies symmetrically across countries. The second measure is the Oxford's lockdown intensity index [18] $\mathrm{stringency}_n$, which varies across countries; here, we maintain the simplifying assumption that a country-wide lockdown intensity applies symmetrically to all its sectors. We calibrate the lockdown intensity as of April 2020 which captures the global lockdown during the initial phase of the pandemic (Figure A2). Given these two measures, we then calibrate the labor supply shock that is specific to a sector-country as follows:

$$\ln \xi_{nj} = \left(1 - \mathrm{WfH}_j\right) \times \mathrm{stringency}_n \qquad (20)$$

Trade, input, and consumption shares. We discipline the supply chain and demand linkages—these relate to the matrices Π^x and Π^f—by calibrating the model to match the OECD ICIO database. [19]

Structural parameters. The remaining structural parameters are calibrated as follows. For the value-added and capital shares in production, we use information from KLEMS and OECD STAN databases. These two shares are calibrated to be sector-specific but averaged across countries to reduce noise. The latter step, however, reduces scope for meaningful cross-country differentiation of our headline results. For the elasticity parameters, we follow Huo et al. (2019) and set all final and intermediate demand elasticities to be unity. These values are smaller than those commonly used in the trade literature. That said, this calibration choice implies

[17] In addition to these two channels, there are compositional changes in the intermediate and final expenditure shares as prices vary, and the actual effect depends on whether goods are complements (i.e. $\rho<1$ or $\varepsilon<1$) or substitutes (i.e. $\rho>1$ or $\varepsilon>1$). In the baseline calibration, we abstract from this channel by assuming these elasticities are unity.

[18] Oxford Blavatnik School of Government Coronavirus Government Response Tracker (Hale et al. 2020).

[19] Though the OECD ICIO database (2018 edition) features 36 sectors, we combine some of them due to limitations of sample coverage in the STAN database, from which we source the value-added and capital shares in production. We use 2015 as the reference year as it is the latest data point. Detailed coverage of countries and sectors are presented in Appendix C.

that preferences as well as production structures are hard to adjust—this is consistent with our interpretation that the impact of the shocks accrue in the very short term. Finally, the Frisch labor supply elasticity is set to 2 in line with Huo et al. (2019) and Bonadio et al. (2020). We perform robustness checks with respect to these parameter choices.

E. Caveats

While the model features the details necessary for the key questions we set out in this paper, it abstracts from other aspects for tractability. We highlight three important ones. First, we abstract from any dynamic features—for instance, savings-consumption decisions. In the absence of any explicit dynamics in the model, we interpret the impact as accruing in the very short term. The assumption of fixed capital, the fact that lockdowns do not have any endogenous impact from an epidemiological perspective, and the calibration of the elasticities would be consistent with this interpretation.[20] Second, the pandemic-induced lockdown is primarily modeled as a labor supply shock. And while this supply shock propagates via supply and demand channels in the model, we do not explicitly consider the role of independent demand shocks, which are also relevant during the pandemic (Brinca, Duarte, and Castro 2020). Third, the model does not feature policy responses, such as, the widely used job retention schemes in Europe. Thus, our framework abstracts away from the mitigating effects—to the extent that they are immediate—of such policy measures during the pandemic.

V. Results

Based on the direction of transmission, we present two sets of results. First, we show the impact on the auto sector—as spillover destination—due to the pandemic-induced lockdowns in sectors and countries. Second, we show how these lockdowns in the auto sector—as spillover source—impact value added in other sectors and countries. We assess the effect of the lockdowns in terms of their impact on real value added. The headline results focus on the average European country. Country-specific estimates for all countries in the OECD-ICIO sample are presented in Appendix Tables A1 and A2.

A. Spillovers to the Auto Sector

Adverse labor supply shocks, as those experienced during the peak of the pandemic in 2020 would have a sizable negative impact on the European auto sector. Figure 18 shows the impact of a global lockdown—i.e., adverse labor supply shocks in all countries and sectors, including the auto sector—on the auto sector in Europe. For the purpose of exposition, this refers to the impact on an “average” European auto sector where we use Domar weights to construct the European average. For comparison, we also present the corresponding impact on other sectors—commodity, other manufacturing, and services—as well as the impact on GDP. As the figure shows, the impact on the European auto sector is quite sizable—a contraction close to 30 percent relative to the steady state. Furthermore, the contraction in the auto sector is more severe compared to other sectors and the overall economy. This reflects, in part, the relatively long and elaborate supply chains in the European auto sector, as discussed earlier. The estimated impact on the auto sector,

[20] A relevant issue is how supply chains endogenously reorganize in response to lockdowns (or more generally, supply chain disruptions). But such a response likely goes beyond the immediate impact of lockdowns. Our analytical framework, thus, abstracts away from this issue.

however, seems smaller than the actual decline during the initial phase of the pandemic (Figure 4B). One plausible explanation is that the model abstracts away from adverse demand shocks which would additionally weigh on the auto sector.

Lockdowns of the kind put in place at the beginning of the pandemic would affect the auto sector mainly through their direct impact on labor supply in the auto sector itself. However, spillovers from shocks in other sectors in the domestic economy and foreign countries are still sizable. Using the linearized solution method, we decompose the impact of pandemic-induced lockdowns on the auto sector into three components: (i) direct impact due to labor supply shocks in the auto sector itself in the domestic economy; (ii) spillovers from labor supply shocks that originate in other sectors in the domestic economy; and (iii) spillovers from labor supply shocks that originate in all sectors in foreign countries. The analysis suggests that about two-third of the total impact of the pandemic-induced lockdowns is attributed to shocks in the auto sector itself (Figure 19). The remaining one-third is due to spillovers from other sectors in the domestic economy and spillovers from foreign countries. Thus, the direct impact dominates, but spillovers via supply chains are sizable. Between spillovers, a larger portion of the supply chain impact is domestic, but foreign spillovers also matter. This is consistent with the fact that sectoral transmission channels are more prominent within the domestic economy than across borders due to stronger input-output linkages (Figures 15 and 17) and iceberg trade costs in the model.

Figure 18. Impact on European Auto Sector

(percentage point)

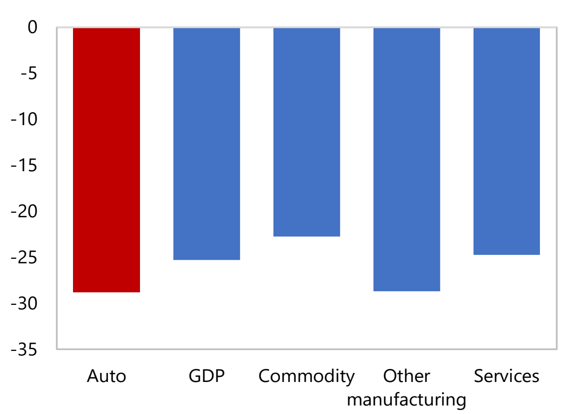
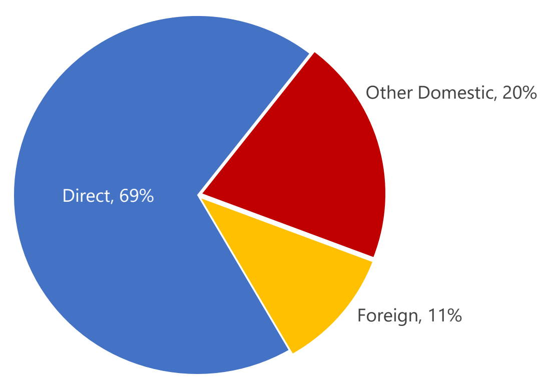


Figure 19. Impact on European Auto Sector: Decomposition

(percent)



Sources: OECD ICIO; IMF staff calculations and estimates.
Note: Impact on real value-added in the global lockdown scenario.

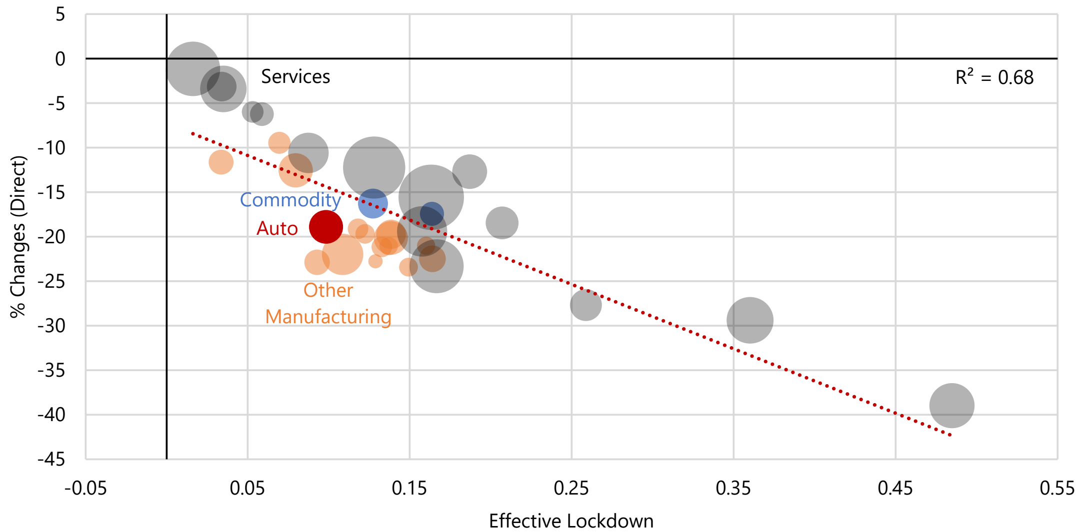
The direct impact of labor supply shocks is related to the extent of the lockdown, but is somewhat proportionately larger in the auto sector. Figure 20 presents a scatter plot of the direct impact of the pandemic-induced lockdowns across sectors and the corresponding "effective" lockdown that augments the labor supply shock in each sector—as calibrated in equation 20—with the importance of labor in each sector.[21] As the fitted trend in the scatter plot illustrates, the direct impact in each sector is broadly proportional to the corresponding effective lockdown—i.e., sectors with more severe lockdowns would have larger negative impacts. One interesting observation is that manufacturing sectors including the auto are generally below the

[21] This importance is measured as the labor input share in sectoral value-added, or equivalently $1 - \alpha_j$.

fitted line, while services and commodity sectors are mostly above the fitted line. This means that adverse labor supply shocks would be amplified in manufacturing sectors.

Figure 20. Lockdowns and the Auto Sector in Europe: Direct Impact vs Effective Lockdown Stringency

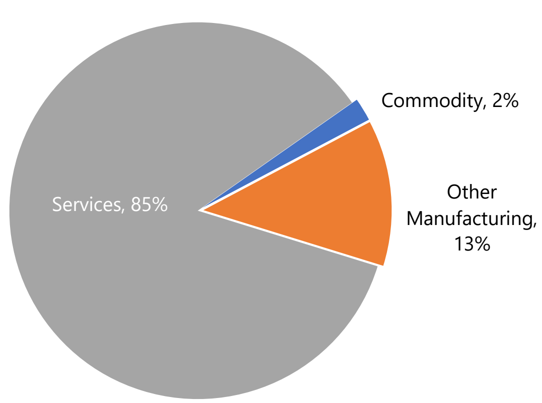
(percentage point, percent)



Sources: OECD ICIO; IMF staff calculations and estimates.
Note: Impact on real value-added in the global lockdown scenario, but focuses only on the direct impact. Effective lockdown refers to sector-specific labor supply shock (equation 20) adjusted for the labor share for that sector. The size of the bubble is proportional to the value-added share of each sector to total value-added.

Figure 21. Impact on European Auto Sector: Domestic Spillovers

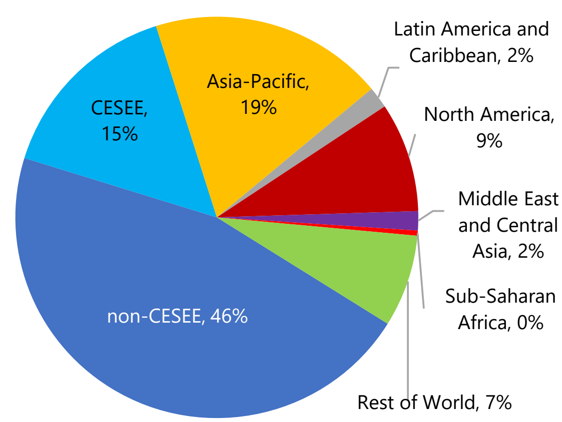
(percent)



Sources: OECD ICIO; IMF staff calculations and estimates.
Note: Impact on real value-added in the global lockdown scenario, but focuses only on domestic spillovers.

Figure 22. Impact on European Auto Sector: Foreign Spillovers

(percent)



Sources: OECD ICIO; IMF staff calculations and estimates.
Note: Impact on real value-added in the global lockdown scenario, but focuses only on foreign spillovers.

Regarding domestic spillovers, labor supply shocks originating in the services sector would have a larger impact on the auto sector relative to shocks originating in other manufacturing. Figure 21 decomposes the domestic spillover to the average European auto sector due to labor supply shocks in other manufacturing sectors as well as the services sector. As the figure shows, domestic spillovers from the services sector are much larger than those from other manufacturing.[22] While this may seem somewhat counterintuitive given that the services sector provides fewer intermediate input for auto production, the services sector is much larger in size relative to the manufacturing sector. [23] In our framework, a larger size translates into larger real income and final demand effects, thus accounting for the larger spillover from the services sector. It is important to emphasize that the general equilibrium framework we deploy is crucial for this result. Spillovers from other manufacturing to the auto sector, on the other hand, primarily reflect transmissions via the supply side through production networks.

Regarding international spillovers, shocks from other European countries dominate, but those from outside the region also matter. We decompose the impact on the auto sector due to labor supply shocks originating in foreign countries. The decomposition is done for each European country, and the results are then aggregated to compute the average for the auto sector across European countries (Figure 22). Labor supply shocks from other European countries account for most of the foreign spillovers. And within this, spillovers originating in non-CESEE would have a larger impact on the European auto sector than those originating in CESEE. Outside of Europe, spillovers originating in Asia-Pacific and North America—though smaller—are still significant. These results are consistent with the regional organization of European auto supply chains, both from supply and demand perspectives. Around 80 percent of intermediate inputs used in the European auto sectors are directly purchased within Europe, thereby implying strong reliance on other European countries' supply chains (Figure 15). From a demand perspective, around 65 percent of the European auto sector value-added is absorbed by final demand in Europe (Figure 17). Within Europe, non-CESEE with their larger economy sizes generate stronger income and demand effects in the model.

Coming to cross-country perspectives, the global lockdown scenario would have a severe impact on the major European auto producers. Figure 23 presents the auto sector impact across European countries in the global lockdown scenario—-i.e. labor supply shocks in all sectors and countries. [24] Our model results suggest that the total impact would be large in countries—such as Italy, Portugal, Slovenia, and the Slovak Republic—where the pandemic-induced lockdowns were the most stringent during the initial phase of the pandemic. On the other hand, in countries such as Germany and Sweden, where the pandemic-induced lockdowns were less stringent, the impact would be milder. Across European countries, the own effect component dominates spillovers—domestic and foreign. And since the own effect is mainly driven by lockdown stringency—as discussed earlier—the cross-country variation in the total impact primarily reflects cross-country variation in stringency. [25]

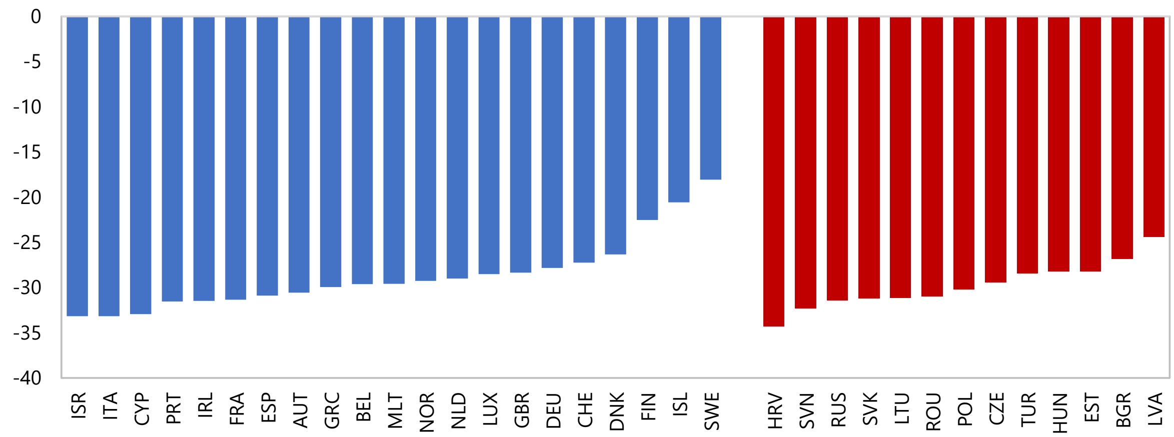
[22] More narrowly, within manufacturing, we have also looked at spillovers from pandemic-induced labor supply shocks that originate in the machinery sector (reflecting semi-conductors). Our model results suggest these spillovers would be small relative to the global lockdown scenario. See Figure A4.

[23] The services sector provides about 23 percent of intermediate input to the European auto sector, while the contribution of other manufacturing is about 34 percent. That said, the size of the services sector is bigger than other manufacturing, as reflected in Figure 25.

[24] Table A1 shows the decomposition of the total impact into own effect, domestic spillovers, and foreign spillovers. Table A2 shows the total impact for the global sample of countries.

[25] Our baseline calibration hardwires some element of symmetry across countries. For instance, the value-added and capital shares are assumed to be the same across countries. Elasticities of substitution are assumed to be unity which removes compositional changes in final and intermediate expenditure shares.

Figure 23. Impact on European Auto Sector
(percentage point)



Sources: OECD ICIO; IMF staff calculations and estimates.
Note: Impact on real value-added in the global lockdown scenario.

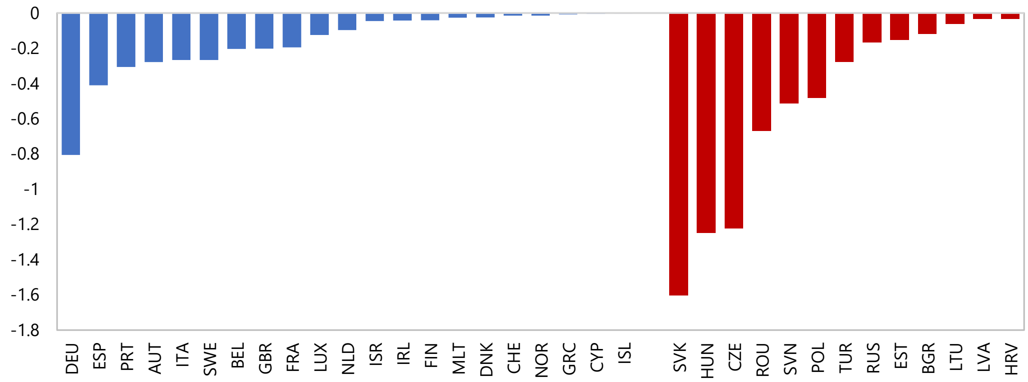
B. Spillovers from the Auto Sector

Labor supply shocks to the auto sector would entail small but non-trivial loss in overall activity. Since the European auto sector is relatively downstream (Figure 16), much of the transmission from a labor supply shock in the auto sector to other sectors (and countries) operates via the demand channel. Of course, such a labor supply shock would have an adverse impact on the auto sector itself. Taken together, Figure 24 shows the impact of such a shock on overall domestic activity—i.e. GDP—in each of the European countries.[26] The impact is small but non-trivial. For instance, German GDP would decline by about 1 percent. In the Slovak Republic, the contraction in GDP would be somewhat larger at about 1.6 percent. The latter result reflects the combined effect of the relatively more severe lockdown and size of the auto sector in the Slovak Republic.

The impact from labor supply shocks in the auto sector on GDP is related to the size of the auto sector. To show this, we compute the domestic GDP impact from shocks in other sectors as well and analyze a scatter plot—relating the impact with the size of the sector (adjusted for the effective lockdown intensity). For exposition, we present the result for Germany (Figure 25). The negative fitted line implies that the larger the sector, the larger would be the adverse impact—another reflection of the demand channel. Thus, the relatively small GDP impact from a labor supply shock in the auto sector—relative to the services sector—reflects the smaller size of the auto sector.[27]

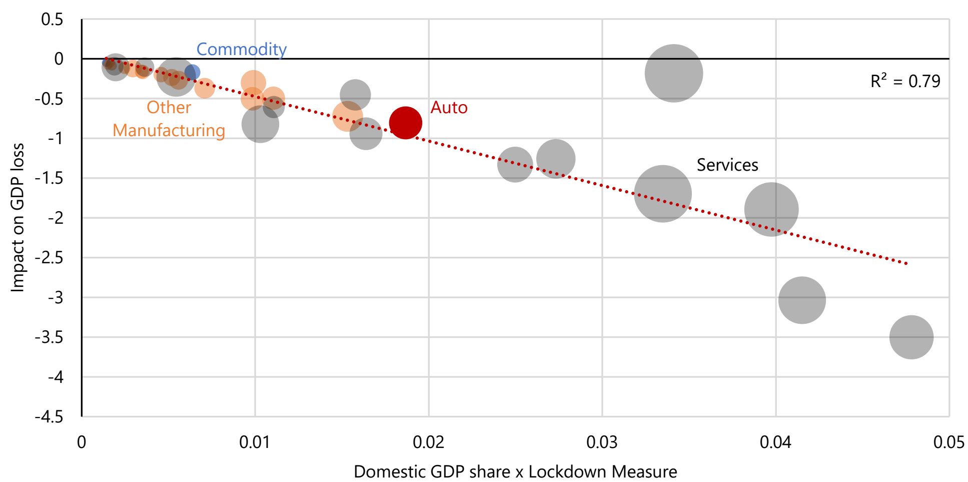
[26] The impact on foreign GDP is tiny in our implementation.
[27] For instance, the auto sector in Germany comprises about 4.5 percent of its GVA, while the corresponding share of the services sector is about 75 percent.

Figure 24. Impact on Real GDP
(percentage point)



Sources: OECD ICIO; IMF staff calculations and estimates.
Note: Impact on real GDP in a given country due to a labor supply shock to the auto sector in that country.

Figure 25. Impact on Real GDP vs. Sectoral Share
(percentage point, percent)



Sources: OECD ICIO; IMF staff calculations and estimates.
Note: Impact on real GDP in Germany due to a labor supply shock to specific sectors in Germany. Size of the bubble is proportional to the value-added share each sector to total value-added.

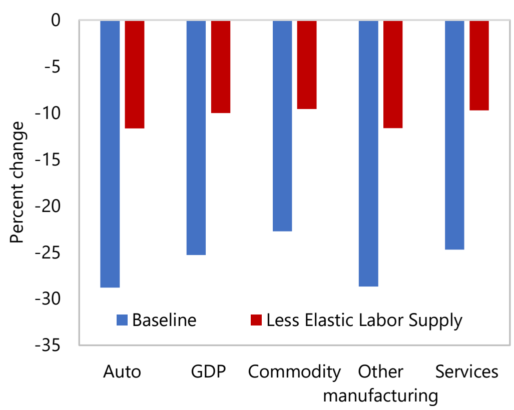
VI. Robustness

Our headline results are broadly robust to alternative calibrations of the model. For robustness, we use alternative calibrations of the Frisch labor elasticity as well as the final demand and intermediate input elasticities. We report the headline result that shows the impact on the European auto sector in the global lockdown scenario (Figure 26). Regarding Frisch elasticity, we use an alternative calibration where labor supply is less elastic. This would imply a weaker response of labor supply and real labor income; and hence, the spillover impact on value added is smaller. Our headline result is not sensitive to the choice of the final demand elasticity. Regarding intermediate input elasticity, the spillover impact is somewhat smaller when inputs are more complementary (ε = 0.2). This is a result that is standard in this class of models (see, for a discussion, Johnson 2014). But the key takeaway is that the estimated spillovers are broadly similar.

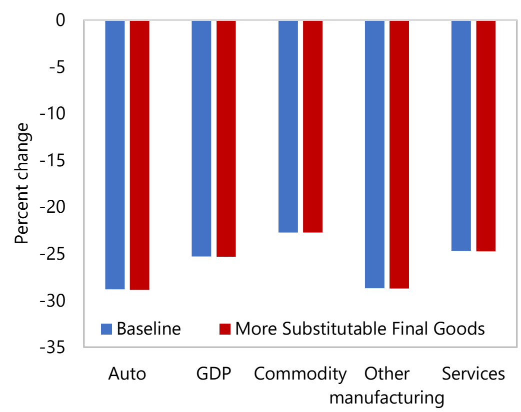
Figure 26. Impact on European Auto Sector: Robustness Exercises

(percentage point)

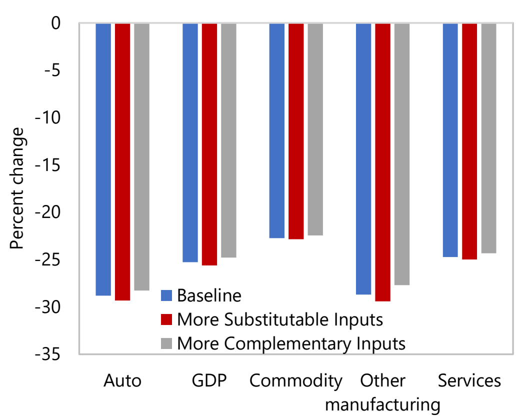
A. Frisch Elasticity



B. Final Demand Elasticity



C. Intermediate Input Elasticity



Sources: OECD ICIO; IMF staff calculations and estimates.

Note: Impact on average European auto sector's real value-added in the global lockdown scenario.

VII. Conclusions

The auto sector is macro-critical in many European countries and constitutes one of the main supply chains in the region. This paper presents a systematic analysis of auto supply chains in European countries. Then, using a multi-sector and multi-country general equilibrium model, it presents a quantitative assessment of the spillover effects of pandemic-induced lockdowns—modeled as adverse labor supply shocks—on the European auto sector and how they propagate via supply chains.

Our results suggest the pandemic-induced labor supply shocks would have a significant adverse impact on the European auto sector, severely affecting major auto producers. One-third of the impact is due to supply chains within and across borders—thus, supply chain linkages are an important transmission mechanism. Within borders, labor supply shocks that originate in the services sector would have a larger spillover impact on the auto sector relative to lockdowns in the manufacturing sector, reflecting the larger size and the associated demand effects of the former. Regarding foreign spillovers, the pandemic-induced lockdowns that originate in other European countries dominate given the regional organization of the European auto sector, but spillovers from those that originate outside the region are still sizable.

Policies to strengthen the resilience of auto supply chains are important. More broadly, our results allude to how supply chain disruptions can spillover and weigh on the auto sector, thus calling for measures to improve the resilience of auto supply chains. Firms can explore better risk management strategies, such as greater diversification of relationships across suppliers, along with greater standardization of input products, and producers holding more inventory of intermediate inputs for just-in-case processes (OECD 2020, 2021). Governments can support firms by collecting and sharing information on potential concentration and bottlenecks upstream.

There are several avenues for future work. First, the pandemic is often characterized as a confluence of demand and supply shocks. Thus, in addition to labor supply shocks as analyzed in this paper, future work could look at the propagation of demand shocks. Such a framework would be particularly useful to better understand the extent to which aggregate demand policies (such as fiscal support) can help mitigate the adverse impact of the pandemic. Second, building on the analytical framework in this paper, future work can examine in greater detail the impact of ongoing supply chain disruptions—beyond labor supply shocks—on the auto sector. In this regard, it would be useful to model other shocks (for instance, shocks to intermediate inputs, transport costs, TFP) and explore the role of inventories (by including the dynamics of capital stock) and the role of input complementarities (using a more elaborate production function). Such an analytical framework would be useful for a quantitative investigation of how the resilience of the auto sector to supply chain disruptions can be improved. Finally, megatrends that preceded the pandemic but are being accelerated by its arrival, such as tighter environmental regulations, reshoring considerations, and automation, could entail significant reorganization of the auto supply chains, shaping the future of the auto sector in Europe.

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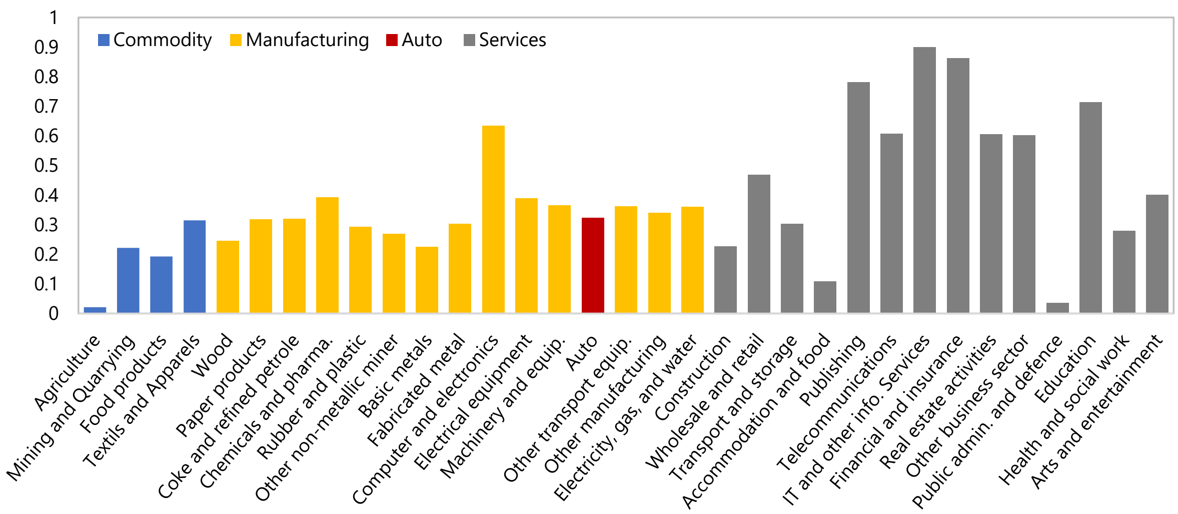
Appendix A. Figures and Tables

Figure A1. Telework Index

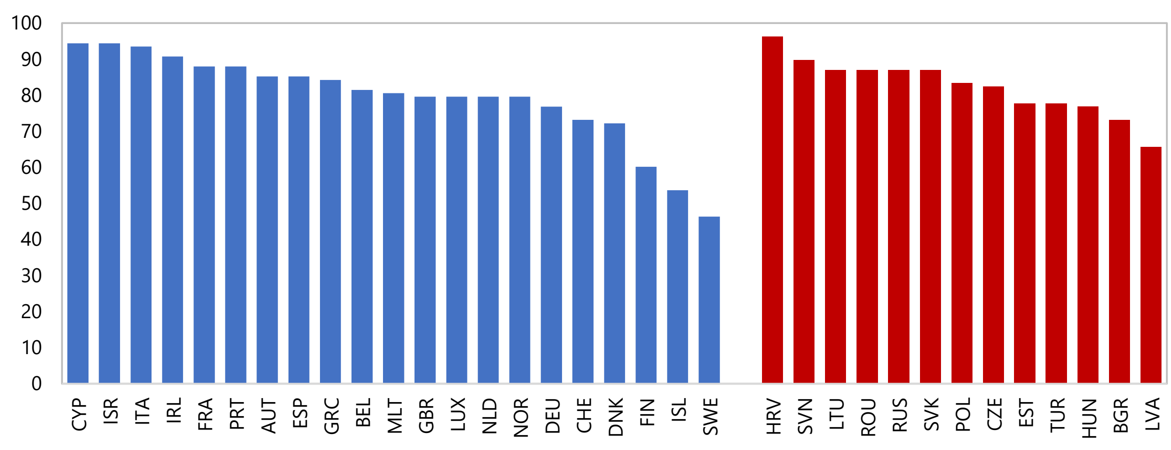
(index)



Source: Dingel and Neiman (2020).
Note: Higher index reflects greater scope for teleworking.

Figure A2. Oxford's Stringency Index

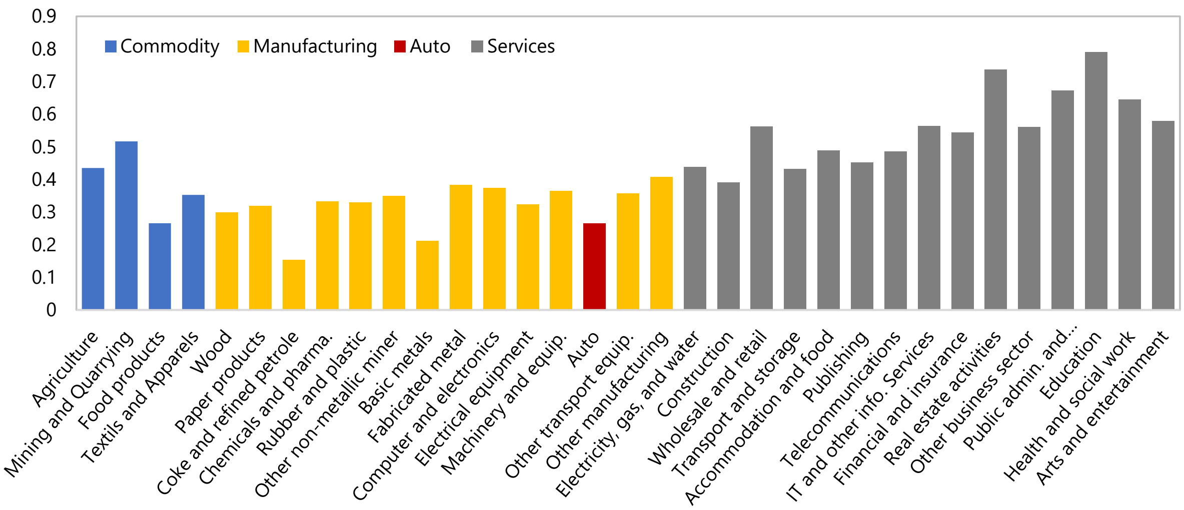
(index)



Source: Oxford Blavatnik School of Government Coronavirus Government Response Tracker (Hale et al. 2020).
Note: Refers to stringency as of April 2020.

Figure A3. Value-Added Share (eta)

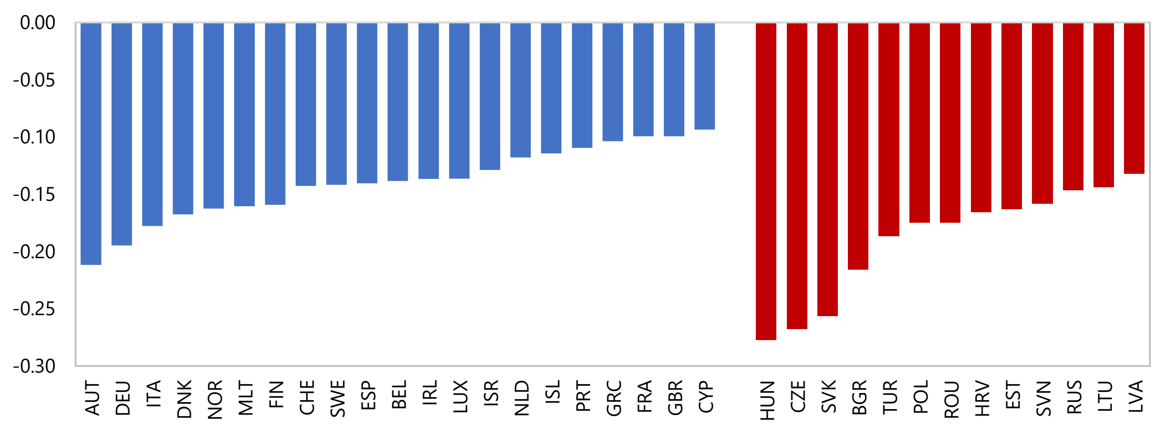
(percent)



Source: OECD STAN database.
Note: This is the average share across countries in the STAN database.

Figure A4. Impact on European Auto Sector: Lockdowns in Machinery Sector

(percent)



Sources: OECD ICIO; IMF staff calculations and estimates.
Note: Impact on real value-added due to lockdowns in the machinery sector.

Table A1. Impact of Labor Supply Shocks on Real Value-Added in the Auto Sector: European Country-Specific Decomposition of Total Impact
(percentage point)

Country	Country Group	Total Impact	Own	Domestic	Foreign
AUT	Non-CESEE	-30.5	-21.1	-5.7	-3.8
BEL	Non-CESEE	-29.6	-20.2	-5.3	-4.1
CHE	Non-CESEE	-27.2	-18.1	-5.6	-3.5
CYP	Non-CESEE	-32.9	-23.4	-5.3	-4.2
DEU	Non-CESEE	-27.8	-19.1	-5.7	-3.0
DNK	Non-CESEE	-26.3	-17.9	-5.0	-3.4
ESP	Non-CESEE	-30.9	-21.1	-6.9	-2.8
FIN	Non-CESEE	-22.5	-14.9	-4.6	-3.0
FRA	Non-CESEE	-31.3	-21.8	-6.7	-2.8
GBR	Non-CESEE	-28.3	-19.7	-5.9	-2.7
GRC	Non-CESEE	-29.9	-20.8	-6.1	-3.0
IRL	Non-CESEE	-31.5	-22.5	-4.1	-4.9
ISL	Non-CESEE	-20.6	-13.3	-3.5	-3.8
ISR	Non-CESEE	-33.2	-23.4	-6.9	-2.9
ITA	Non-CESEE	-33.1	-23.2	-7.5	-2.5
LUX	Non-CESEE	-28.5	-19.7	-4.6	-4.1
MLT	Non-CESEE	-29.6	-19.9	-4.7	-4.9
NLD	Non-CESEE	-29.0	-19.7	-6.0	-3.3
NOR	Non-CESEE	-29.2	-19.7	-6.3	-3.2
PRT	Non-CESEE	-31.5	-21.8	-6.2	-3.5
SWE	Non-CESEE	-18.1	-11.5	-3.3	-3.2
BGR	CESEE	-26.8	-18.1	-4.4	-4.3
CZE	CESEE	-29.4	-20.5	-4.8	-4.2
EST	CESEE	-28.2	-19.3	-4.5	-4.4
HRV	CESEE	-34.3	-23.8	-6.7	-3.8
HUN	CESEE	-28.2	-19.1	-4.3	-4.8
LTU	CESEE	-31.1	-21.5	-4.9	-4.7
LVA	CESEE	-24.4	-16.3	-4.4	-3.7
POL	CESEE	-30.2	-20.7	-5.8	-3.7
ROU	CESEE	-31.0	-21.6	-5.9	-3.4
RUS	CESEE	-31.4	-21.6	-7.6	-2.3
SVK	CESEE	-31.2	-21.6	-4.9	-4.6
SVN	CESEE	-32.3	-22.3	-5.7	-4.3
TUR	CESEE	-28.4	-19.3	-6.3	-2.8
Non-CESEE		**-28.5**	**-19.6**	**-5.9**	**-3.0**
CESEE		**-29.9**	**-20.6**	**-5.6**	**-3.7**
Europe		**-28.8**	**-19.8**	**-5.8**	**-3.1**

Sources: OECD ICIO; IMF staff calculations and estimates.

Note: Impact on real value-added in the global lockdown scenario.

Table A2. Impact of Labor Supply Shocks on Real Value-Added in the Auto Sector: Country-Specific Results
(percentage point)

Country	Country Group	Total Impact	Country	Country Group	Total Impact
AUT	Non-CESEE	-30.5	AUS	Asia-Pacific	-26.3
BEL	Non-CESEE	-29.6	BRN	Asia-Pacific	-22.4
CHE	Non-CESEE	-27.2	CHN	Asia-Pacific	-29.8
CYP	Non-CESEE	-32.9	HKG	Asia-Pacific	-24.5
DEU	Non-CESEE	-27.8	IDN	Asia-Pacific	-29.1
DNK	Non-CESEE	-26.3	IND	Asia-Pacific	-35.2
ESP	Non-CESEE	-30.9	JPN	Asia-Pacific	-17.8
FIN	Non-CESEE	-22.5	KHM	Asia-Pacific	-25.4
FRA	Non-CESEE	-31.3	KOR	Asia-Pacific	-30.0
GBR	Non-CESEE	-28.3	MYS	Asia-Pacific	-26.5
GRC	Non-CESEE	-29.9	NZL	Asia-Pacific	-33.4
IRL	Non-CESEE	-31.5	PHL	Asia-Pacific	-34.6
ISL	Non-CESEE	-20.6	SGP	Asia-Pacific	-30.1
ISR	Non-CESEE	-33.2	THA	Asia-Pacific	-28.1
ITA	Non-CESEE	-33.1	TWN	Asia-Pacific	-13.1
LUX	Non-CESEE	-28.5	VNM	Asia-Pacific	-34.0
MLT	Non-CESEE	-29.6			
NLD	Non-CESEE	-29.0	CHL	Latin America and the Caribbean	-26.6
NOR	Non-CESEE	-29.2	ARG	Latin America and the Caribbean	-35.3
PRT	Non-CESEE	-31.5	BRA	Latin America and the Caribbean	-28.2
SWE	Non-CESEE	-18.1	COL	Latin America and the Caribbean	-32.7
			CRI	Latin America and the Caribbean	-29.2
BGR	CESEE	-26.8	PER	Latin America and the Caribbean	-34.9
CZE	CESEE	-29.4			
EST	CESEE	-28.2	CAN	North America	-26.9
HRV	CESEE	-34.3	MEX	North America	-29.0
HUN	CESEE	-28.2	USA	North America	-26.4
LTU	CESEE	-31.1			
LVA	CESEE	-24.4	KAZ	Middle East and Central Asia	-32.0
POL	CESEE	-30.2	MAR	Middle East and Central Asia	-33.6
ROU	CESEE	-31.0	SAU	Middle East and Central Asia	-33.6
RUS	CESEE	-31.4	TUN	Middle East and Central Asia	-34.9
SVK	CESEE	-31.2			
SVN	CESEE	-32.3	ZAF	Sub-Saharan Africa	-32.8
TUR	CESEE	-28.4			
			Asia Pacific		**-26.7**
Non-CESEE		**-28.5**	**Latin America and the Caribbean**		**-30.1**
CESEE		**-29.9**	**North America**		**-26.9**
Europe		**-28.8**	**Middle East and Central Asia**		**-33.9**

Sources: OECD ICIO; IMF staff calculations and estimates.
Note: Impact on real value-added in the global lockdown scenario.

Appendix B. Model derivations

The responses of gross output, hours, and value-added to labor supply shocks are derived from three sets of equilibrium conditions: the goods market clearing conditions, where we have the relationship between output Y_{nj} and prices P_{nj}; the labor market clearing conditions, where we have the relationship between revenue $P_{nj}Y_{nj}$, real wages $\frac{W_{nj}}{P_n}$, labor supply shock ξ_{nj} and labor supply H_{nj}; and the production optimization conditions, where we have the relationship between output Y_{nj}, production factors $\{H_{nj}, X_{nj}\}$, and prices $\{P_{nj}, W_{nj}, P^x_{nj}\}$. Following Huo et al. (2019) and Bonadio et al. (2020), we log-linearize all the above equilibrium conditions around the steady state values and derive the influence matrix.

Goods Market Clearing Conditions. The log-linearized version of the goods market clearing conditions is:

$$\ln P_{nj} + \ln Y_{nj} = mi\frac{\omega_{mj}\pi^c_{nmj}P_mF_m}{P_{nj}Y_{nj}}\frac{\eta_iP_{mi}Y_{mi}}{P_mF_m}\left(\ln P_{mi} + \ln Y_{mi} + \ln \pi^c_{nmj}\right)$$
$$+\sum_m\sum_i\frac{(1-\eta_i)\pi^x_{nj,mi}P_{mi}Y_{mi}}{P_{nj}Y_{nj}}\left(\ln P_{mi} + \ln Y_{mi} + \ln \pi^x_{nj,mi}\right) \quad (A1)$$

where the log-deviation of expenditure shares are given by:

$$\ln \pi^c_{nmj} = (1-\rho)\sum_k \pi^c_{kmj}\left(\ln P_{nj} - \ln P_{kj}\right)$$
$$\ln \pi^x_{nj,mi} = (1-\varepsilon)\sum_{k,l} \pi^x_{kl,mi}\left(\ln P_{nj} - \ln P_{kl}\right)$$

Define the following matrices containing essential shares:

1. $\boldsymbol{\Psi^c}$ is an $NJ\times N$ matrix whose (nj,m)th element is $\frac{\omega_{mj}\pi^c_{nmj}P_mF_m}{P_{nj}Y_{nj}}$.
2. $\boldsymbol{\Psi^x}$ is an $NJ\times NJ$ matrix whose (nj,mi)th element is $\frac{(1-\eta_i)pi^x_{nj,mi}P_{mi}Y_{mi}}{P_{nj}Y_{nj}}$.
3. $\boldsymbol{\Upsilon}$ is an $N\times NJ$ matrix whose (n,mi)th element is $\frac{\eta_iP_{mi}Y_{mi}}{P_mF_m}$.
4. $\boldsymbol{\Pi^c}$ is an $N\times NJ$ matrix whose (m,kj)th element is π^c_{kmj}.
5. $\boldsymbol{\Pi^x}$ is an $NJ\times NJ$ matrix whose (kl,mi)th element is $\pi^x_{mi,kl}$.

Then, we can rewrite equation (A1) above into matrix form:

$$\ln \boldsymbol{P} + \ln \boldsymbol{Y} = \underbrace{\boldsymbol{\Psi^c\Upsilon}(\ln \boldsymbol{P} + \ln \boldsymbol{Y})}_{Final\ Demand\ /Income\ Effect} + \underbrace{\boldsymbol{\Psi^x}(\ln \boldsymbol{P} + \ln \boldsymbol{Y})}_{Supply\ Chain\ Effect}$$

$$+\underbrace{(1-\rho)(diag(\boldsymbol{\Psi^c 1}) - \boldsymbol{\Psi^c\Pi^c})\ln \boldsymbol{P}}_{\text{Compositional Effect (Final)}} + \underbrace{(1-\varepsilon)(diag(\boldsymbol{\Psi^x 1}) - \boldsymbol{\Psi^x\Pi^x})\ln \boldsymbol{P}}_{\text{Compositional Effect (Intermediate)}} \quad (A2)$$

This condition allows us to express price deviations as a linear transformation of output deviations:

$$\ln \boldsymbol{P} = A_p \ln \boldsymbol{Y} \quad (A3)$$

where

$$A_p = -(I - M)^{+}(I - \mathbf{\Psi}^c\mathbf{\Upsilon} - \mathbf{\Psi}^x)$$
$$M = \mathbf{\Psi}^c\mathbf{\Upsilon} + \mathbf{\Psi}^x + (1-\rho)(diag(\mathbf{\Psi}^c\mathbf{1}) - \mathbf{\Psi}^c\mathbf{\Pi}^c) + (1-\varepsilon)(diag(\mathbf{\Psi}^x\mathbf{1}) - \mathbf{\Psi}^x\mathbf{\Pi}^x)$$

Labor Market Clearing Conditions. The labor demand function implies:

$$\ln \boldsymbol{W} - \ln \boldsymbol{P} = \ln \boldsymbol{Y} - \ln \boldsymbol{H}$$

From labor supply, we have:

$$\ln \boldsymbol{H} = \psi(\ln \boldsymbol{W} - \ln \boldsymbol{P}^f - \ln \boldsymbol{\xi})$$

where $\ln \boldsymbol{P}^f = (\mathbf{\Pi}^f \otimes \mathbf{1}) \ln \boldsymbol{P}$ is the consumption price index that prevails at each sector within each country. These conditions imply the following equilibrium relationship for hours supplied:

$$\ln \boldsymbol{H} = \frac{\psi}{\psi+1}\ln \boldsymbol{Y} + \frac{\psi}{\psi+1}\left(I - \mathbf{\Pi}^f \otimes \mathbf{1}\right)\ln \boldsymbol{P} - \frac{\psi}{\psi+1}\ln \boldsymbol{\xi} \qquad (A4)$$

Production Optimization Conditions. The production function implies the following relation between deviations of output, hours, and intermediate inputs:

$$\ln \boldsymbol{Y} = \boldsymbol{\eta}(I - \boldsymbol{\alpha})\ln \boldsymbol{H} + (I - \boldsymbol{\eta})\ln \boldsymbol{X} \qquad (A5)$$

Based on the optimization choice of intermediate inputs, we have:

$$\ln \boldsymbol{P}^x - \ln \boldsymbol{P} = \ln \boldsymbol{Y} - \ln \boldsymbol{X}$$

where $\ln \boldsymbol{P}^x = \mathbf{\Pi}^x \ln \boldsymbol{P}$ is the vector of intermediate input price indices for all countries and sectors. Jointly, these imply:

$$\ln \boldsymbol{X} = \ln \boldsymbol{Y} + (I - \mathbf{\Pi}^x) ln\boldsymbol{P} \qquad (A6)$$

Plugging conditions (A3), (A4) and (A6) into (A5), we have the following condition between the vector of gross output and the vector of labor supply shocks:

$$\ln Y = -A_z \frac{\psi}{\psi+1}\boldsymbol{\eta}(I - \boldsymbol{\alpha})\ln \boldsymbol{\xi}$$

Where

$$A_z = \left[I - \frac{\psi}{\psi+1}\boldsymbol{\eta}(I - \boldsymbol{\alpha})\left(I + (I - \mathbf{\Pi}^f \otimes \mathbf{1})A_p\right) - (I - \boldsymbol{\eta})\left(I + (I - \mathbf{\Pi}^x)A_p\right)\right]^{-1}$$

The response of hours (labor supply) can be derived using (A4) in a similar fashion.

Appendix C. List of Countries and Sectors

1. Countries covered in OECD ICIO and Regional Classification

ISO 3	European Economies	Classification	ISO 3	Non-European Economies	Classification
AUT	Austria	Non-CESEE	AUS	Australia	Asia Pacific
BEL	Belgium	Non-CESEE	JPN	Japan	Asia Pacific
CYP	Cyprus	Non-CESEE	KOR	Korea Republic	Asia Pacific
DNK	Denmark	Non-CESEE	NZL	New Zealand	Asia Pacific
FIN	Finland	Non-CESEE	BRN	Brunei Darussalam	Asia Pacific
FRA	France	Non-CESEE	KHM	Cambodia	Asia Pacific
DEU	Germany	Non-CESEE	CHN	China (People's Republic of)	Asia Pacific
GRC	Greece	Non-CESEE	IND	India	Asia Pacific
ISL	Iceland	Non-CESEE	IDN	Indonesia	Asia Pacific
IRL	Ireland	Non-CESEE	HKG	Hong Kong, China	Asia Pacific
ISR	Israel	Non-CESEE	MYS	Malaysia	Asia Pacific
ITA	Italy	Non-CESEE	PHL	Philippines	Asia Pacific
LUX	Luxembourg	Non-CESEE	SGP	Singapore	Asia Pacific
MLT	Malta	Non-CESEE	TWN	Chinese Taipei	Asia Pacific
NLD	Netherlands	Non-CESEE	THA	Thailand	Asia Pacific
NOR	Norway	Non-CESEE	VNM	Viet Nam	Asia Pacific
PRT	Portugal	Non-CESEE	CHL	Chile	Latin America and the Caribbean
ESP	Spain	Non-CESEE	ARG	Argentina	Latin America and the Caribbean
SWE	Sweden	Non-CESEE	BRA	Brazil	Latin America and the Caribbean
CHE	Switzerland	Non-CESEE	COL	Colombia	Latin America and the Caribbean
GBR	United Kingdom	Non-CESEE	CRI	Costa Rica	Latin America and the Caribbean
BGR	Bulgaria	CESEE	PER	Peru	Latin America and the Caribbean
HRV	Croatia	CESEE	KAZ	Kazakhstan	Middle East and Central Asia
CZE	Czech Republic	CESEE	MAR	Morocco	Middle East and Central Asia
EST	Estonia	CESEE	SAU	Saudi Arabia	Middle East and Central Asia
HUN	Hungary	CESEE	TUN	Tunisia	Middle East and Central Asia
LVA	Latvia	CESEE	CAN	Canada	North America
LTU	Lithuania	CESEE	MEX	Mexico	North America
POL	Poland	CESEE	USA	United States	North America
ROU	Romania	CESEE	ZAF	South Africa	Sub-Saharan Africa
RUS	Russian Federation	CESEE	ROW	Rest of the World	NA
SVK	Slovak Republic	CESEE			
SVN	Slovenia	CESEE			
TUR	Turkey	CESEE			

2. Sectors covered in OECD ICIO

Code	Industry	ISIC Rev.4
01T03	Agriculture, forestry and fishing	01, 02, 03
05T06	Mining and extraction of energy producing products	05, 06
07T08	Mining and quarrying of non-energy producing products	07, 08
09	Mining support service activities	09
10T12	Food products, beverages and tobacco	10, 11, 12
13T15	Textiles, wearing apparel, leather and related products	13, 14, 15
16	Wood and products of wood and cork	16
17T18	Paper products and printing	17, 18
19	Coke and refined petroleum products	19
20T21	Chemicals and pharmaceutical products	20, 21
22	Rubber and plastic products	22
23	Other non-metallic mineral products	23
24	Basic metals	24
25	Fabricated metal products	25
26	Computer, electronic and optical products	26
27	Electrical equipment	27
28	Machinery and equipment, nec	28
29	Motor vehicles, trailers and semi-trailers	29
30	Other transport equipment	30
31T33	Other manufacturing; repair and installation of machinery and equipment	31, 32, 33
35T39	Electricity, gas, water supply, sewerage, waste and remediation services	35,36, 37, 38, 39
41T43	Construction	41, 42, 43
45T47	Wholesale and retail trade; repair of motor vehicles	45, 46, 47
49T53	Transportation and storage	49, 50, 51, 52, 53
55T56	Accommodation and food services	55, 56
58T60	Publishing, audiovisual and broadcasting activities	58, 59, 60
61	Telecommunications	61
62T63	IT and other information services	62, 63
64T66	Financial and insurance activities	64, 65, 66
68	Real estate activities	68
69T82	Other business sector services	69, 70, 71, 72, 73, 74, 75, 77, 78, 79, 80, 81, 82
84	Public admin. and defense; compulsory social security	84
85	Education	85
86T88	Human health and social work	86, 87, 88

Note: In the quantitative analysis, 05T06, 07T08 and 09 are aggregated up to one sector (Mining and Quarrying); 90T96 and 97T98 are aggregated up to one sector (Arts, entertainment, other services, households activities).

PUBLICATIONS

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