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Supply Bottlenecks: Where, Why, How Much, and What Next?

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ABSTRACT: Supply constraints hurt the economic recovery and boosted inflation in 2021. We find that in the euro area, manufacturing output and GDP would have been about 6 and 2 percent higher, respectively, and half of the rise in manufacturing producer price inflation would not have occurred in the absence of supply bottlenecks. Sectors that are more reliant on differentiated inputs—such as autos—were harder hit. Globally, shutdowns can explain up to 40 percent of the supply shocks. Late last year industry experts expected supply shortages for autos to largely dissipate by mid-2022 and broader bottlenecks by end-2022, but given the Omicron wave, disruptions will last for longer, possibly into 2023. With supply constraints adding to price pressures, the challenge for policymakers is to support the recovery without allowing high inflation to become entrenched.

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WORKING PAPERS

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INTRODUCTION

1. **Supply bottlenecks have emerged as a key headwind to the economic recovery and boosted inflation, raising important policy issues.** Amidst a shift in global consumer spending towards goods, supplier delivery times have risen to historic highs, non-energy goods prices have surprised on the upside, and manufacturing output weakened in some countries in 2021. How should macroeconomic policies adapt to these developments, if at all? The answer depends largely on whether the bottlenecks stem from higher demand or disrupted supply, and how persistent those shifts may be.

2. **Against that backdrop, this paper focuses on the manufactured goods sector and seeks to answer the following questions:**

1) What are the relative contributions of demand- and supply-side factors to the weakness in manufacturing output and the increase in non-energy goods prices?

2) How much have shutdowns and labor scarcity contributed to the supply bottlenecks in manufacturing? Why are some sectors affected more by the shutdowns?

3) What explains the semiconductor shortages that have been holding back auto production?

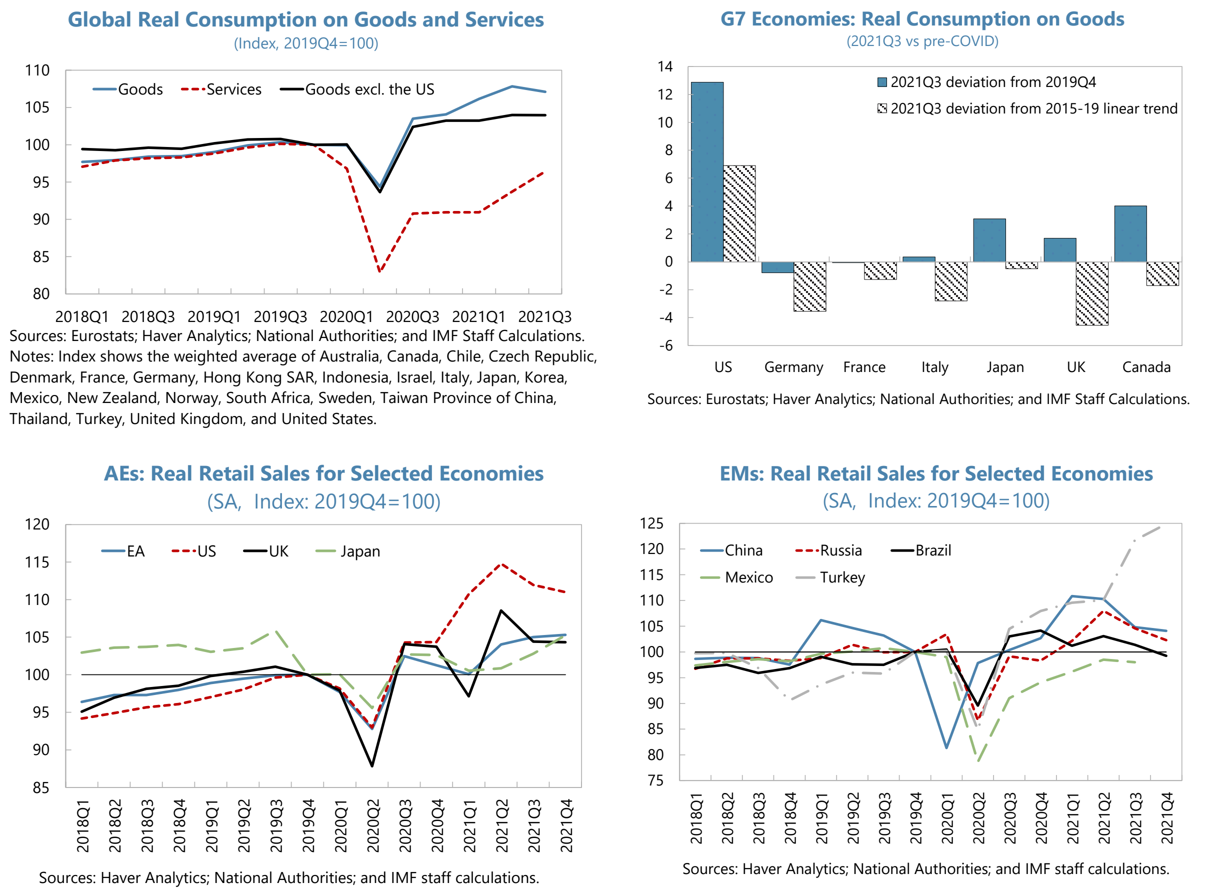
4) When do industry experts think the bottlenecks might ease, and what are the implications for macroeconomic projections and policies?

3. **The paper is organized as follows.** The next section lays out the key stylized facts. The following section discusses the various ways in which supply may be constrained, distinguishing between disruptions and rigidities. The third section presents estimates of how much demand and supply have contributed to key macroeconomic variables—manufacturing output, producer price inflation for manufactured goods, core consumer price inflation, and GDP—in several large economies in 2021. The fourth section explores how much of the supply shocks estimated in the third section can be explained by shutdowns and labor shortages. The fifth section looks at the backlogs in the semiconductor market, which have weighed on auto production. The sixth section considers when the bottlenecks might ease and presents scenarios for GDP and inflation. The seventh section discusses the takeaways and policy implications.

STYLIZED FACTS

4. The pandemic has shifted the composition of spending towards goods. Since the reopening of economies in Spring 2020, household spending on goods aggregated over several large economies has risen above its pre-pandemic trend, driven to a very large extent by strong spending in the United States (Figure 1). Multiple factors are behind the shift, including repressed spending on contact-intensive services and higher demand for goods that help people work, learn, and play at home, and keep safe distances. Continued infection waves and an overhang of excess household savings in many countries—reflecting depressed spending on services and strong income-support measures during the pandemic—could keep the global demand for goods buoyant for some time.[1]

Figure 1. Real Private Consumption

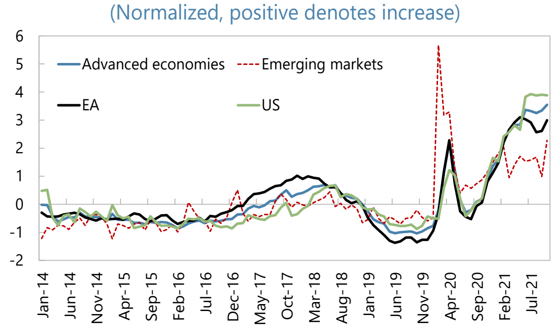


[1] Households in the euro area are estimated to have accumulated about 8 percent of GDP in "excess savings" during the pandemic (as of mid-2021, see IMF Country Report No. 2022/029). Pent-up demand for services is usually limited, so part of the forced savings could be spent on goods over time, including on items that were scarce during the pandemic, such as autos.

5. At the same time, shortages of intermediate inputs and labor, together with jammed logistical systems, have constrained supply. Delivery times for goods have risen well above pre-pandemic norms, especially in advanced economies (Figure 2, top left), and production has not kept up with new orders in many countries (Figure 2, top right).[2] High shares of producers (including more than half in the euro area) are reporting that shortages of intermediate inputs constrain their output (Figure 2, bottom left). The share of firms reporting labor shortages has also risen, albeit to a lesser extent than for intermediate goods, with more acute labor shortages in the US than in the euro area (Figure 2, bottom right). Logistical bottlenecks are another choke point— many ports have seen severe congestion with shipping volumes running above pre-pandemic levels and pandemic restrictions interrupting activity.[3] Reflecting all these headwinds, industrial production (IP) has lost momentum, falling outright in some countries including Germany (in most months of 2021) and Japan (in September and October).

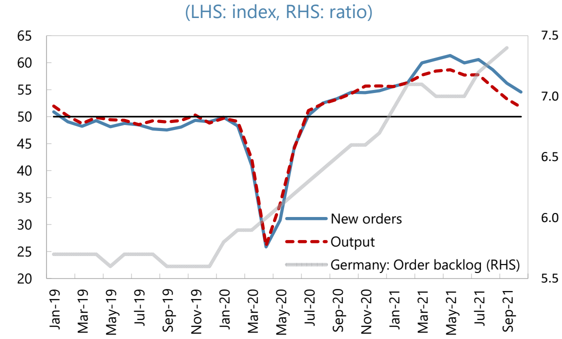
Figure 2. Supply Bottlenecks

Suppliers Delivery Times: AEs, EMs, EA and US
(Normalized, positive denotes increase)



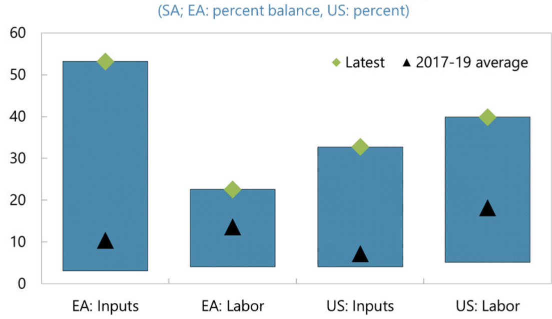
Sources: Haver Analytics; IHS Markit; and IMF staff calculations.
Notes: Advanced economies include the UK, Germany, France, Spain, Ireland, Netherlands, Austria, Greece, Denmark, Switzerland, U.S., Canada, Japan, Australia, and New Zealand. Emerging markets include Brazil, China, Egypt, India, Indonesia, Malaysia, Mexico, Nigeria, Philippines, Poland, Russia, Saudi Arabia, South Africa, Thailand, Turkey, United Arab Emirates,and Vietnam.

G7: Manufacturing PMI Output and New Orders
(LHS: index, RHS: ratio)



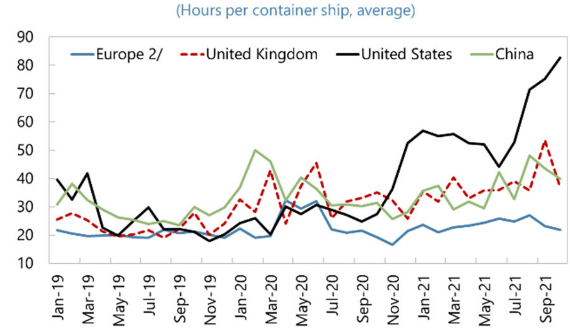
Sources: Destatis; Haver Analytics; IHS Markit; and IMF staff calculations.

Share of Producers Reporting Shortages of Inputs and Labor
(SA; EA: percent balance, US: percent)



Sources: Eurostat; Haver Analytics; U.S. Census Bureau; and IMF staff calculations.
Notes: The latest data were 2021Q2 for US and 2021Q4 for EA19. The blue bars show the range values between 2013Q1 and the latest.

Waiting Time in Ports 1/
(Hours per container ship, average)



Sources: Marine Traffic; Cerdeiro, Komaromi, Liu, and Saeed (2021); and IMF staff calculations.
Notes: 1/ Average number of hours container ships at anchorage have waited to enter ports.
2/ Germany, Belgium, Netherlands, France, Portugal, Spain, Italy, and Greece.

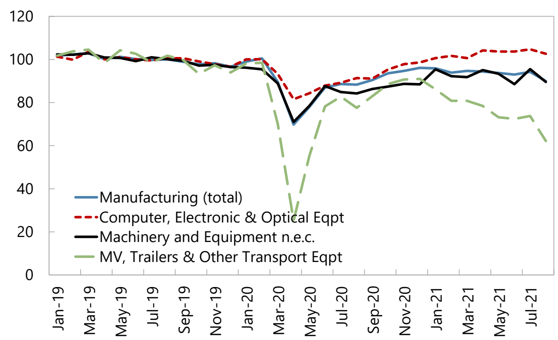
[2] The strength in new orders may in part reflect an anticipation of continued product shortages, and a precautionary buildup of buffers and hoarding at different stages of supply chains (the "bullwhip effect"; BIS 2021).

[3] Problems are widespread but seem most severe in the United States. Annex 1 examines the drivers of port congestion.

6. **Motor vehicle output has been constrained by a scarcity of microchips.** While many industrial sectors are facing bottlenecks, the motor vehicles sector has been the hardest hit (Figure 3). This is consistent with the sector being the one where reported input shortages are the most prevalent (Figure 3, bottom right). Ample anecdotal evidence and media reports indicate that automakers have been facing significant delays in procuring essential microchips.

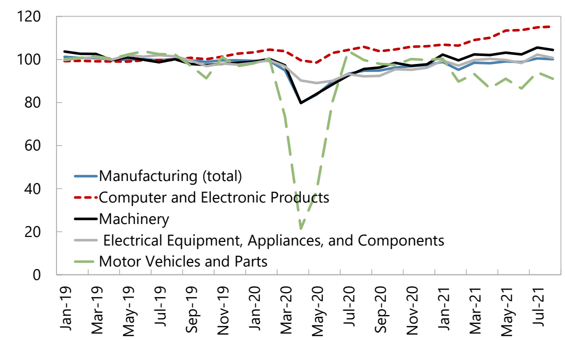
Figure 3. Auto Sector: Production and Shortages of Intermediate Inputs

Germany: Manufacturing Production
(Index: 2019=100)



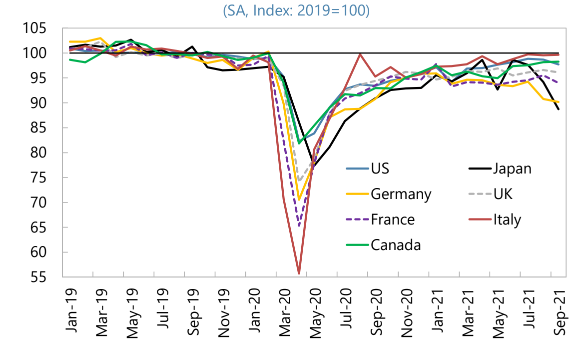
Sources: Eurostat; Haver Analytics; and IMF staff calculations.

US: Manufacturing Production
(Index: 2019=100)



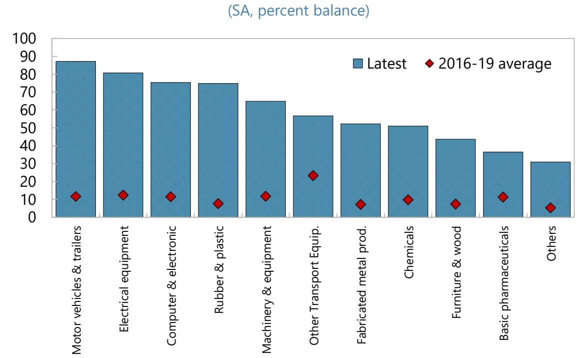
Sources: Federal Reserve Board; Haver Analytics; and IMF staff calculations.

Industrial Production
(SA, Index: 2019=100)



Sources: Haver; and IMF staff calculations.
Note: Data for Mexico are IP incl. construction, while for others are IP excl. construction.

EA19: Equipment limiting Production by Sector
(SA, percent balance)



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

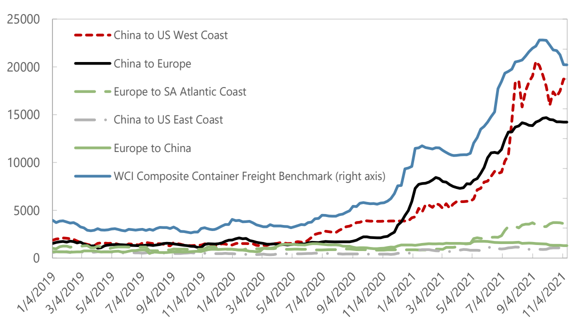
7. **Bottlenecks have also pushed up inflation.** International shipping costs have soared as transportation systems came under strain, with some partial easing recently (Figure 4, left). Energy prices stood 50 percent above their 2019 level in 2021Q3, following a 33 percent fall in 2020. Reflecting higher input costs and margins in sectors facing strong demand—PPI inflation has risen sharply in most countries (Figure 4, right)[4]. All in all, the manufacturing component of PPI inflation in the euro area was about 10

[4] Physical distancing and other precautionary measures imposed at work sites during the pandemic may also have raised production costs in some countries and sectors.

percentage points higher in the third quarter of 2021 than in 2017–19, 14 percentage points higher in the United States, and 6 percentage points higher in United Kingdom. Higher prices soften demand and draw productive resources into sectors where supply is falling short, helping to balance markets. But a large and sustained rise in costs due to bottlenecks can harm the recovery, both by lifting consumer prices and cutting into households' purchasing power, and indirectly by leading central banks to tighten monetary policy sooner to prevent inflation expectations from shifting above target.

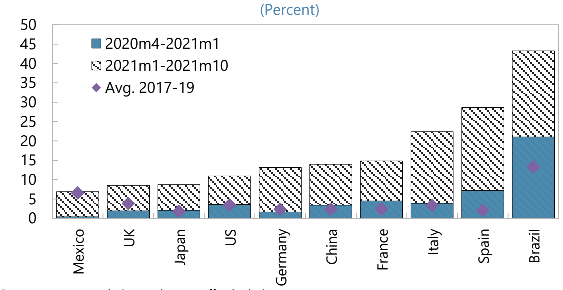
Figure 4. Shipping rates and Manufacturing PPI Inflation

Shipping Rates
(USD per 40 foot box; index, 2019=100)



Source: Bloomberg

Change in Producer Prices
(Percent)



Sources: Haver Analytics; and IMF staff calculations.
Notes: The average change over 2017-19 is calculated by using an average 18-month inflation rate between 2017m1-2018m6 and 2018m7-2019m12. The PPI series used in the chart are: "PPI: Industry excl. construction" (Germany, France, Italy, and Spain), "PPI: Final demand" (US), "PPI: Output of manufactured products excl. duty" (UK), "PPI: Manufacturing industry products" (Japan), "PPI: All industry products" (China and Brazil), and "PPI: Total production excl. oil and services" (Mexico).

CONCEPTUAL FRAMEWORK—VARIETIES OF SUPPLY CONSTRAINTS

8. Multiple factors have restrained manufacturing activity during the pandemic, causing output to fall or preventing it from rising enough to satisfy the higher level of demand. Lockdowns have disrupted production and transportation, reducing supply temporarily. Lower labor supply than before the pandemic, due to health or family care concerns, is also an example of a disruption, albeit possibly with a persisting component as some people might retire early or permanently reduce their working hours. By contrast, the fixed supply of containers and shipping fleets in the short run, obstacles to reallocating workers from shrinking to growing sectors, or insufficient numbers of workers with the newly needed skills are rigidities that prevent supply from catching up with the rise in demand. Such rigidities would be expected to ease gradually, as new containers or newly skilled workers become available. These effects are depicted in Figures 5a and 5b:

- **Rigidities.** The difficulties in expanding supply would be represented by the supply curve being steeper beyond a level of output (the curve S_0 in Figure 5a). Over time, if new capital investments are made (e.g., new shipping containers manufactured, and microchip factories expanded or built) or as barriers to greater labor supply and reallocation are overcome, the supply curve could flatten (curve S_1) and prices could fall. Until supply expands, prices would stay high if demand remains strong. This type of supply constraint would fade quickly if demand were to recede.
- **Disruptions.** The effect of declines in supply due to lockdowns or disasters is equivalent to a temporary inward shift in the supply curve (S_0 to S_1 in Figure 5b). In this case, the interaction of strong demand (an outward shift in the demand curve) and temporarily reduced supply would limit the increase in output (or even reduce it) and inflate prices. Shutdowns, or a pandemic-driven decline in labor supply, would be represented by an inward shift in the supply curve. An inward shift due to shutdowns should be transient. A shift due to softer labor supply could in part be permanent, reflected in early retirements and a lasting departure of migrant workers, or a preference for reduced work hours, and in part temporary, with immigration normalizing or people returning to work once infections recede or when their liquidity buffers run out.

Figure 5a. Demand and Supply Shock

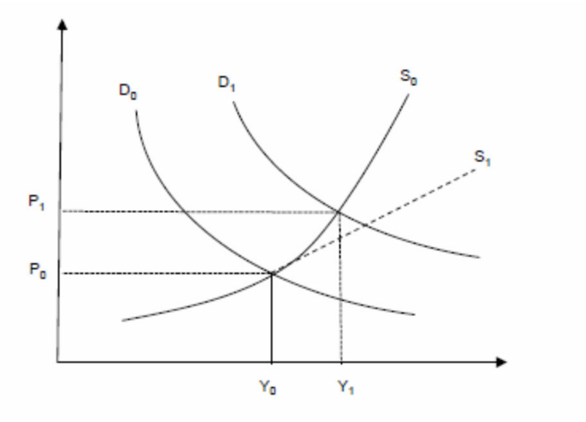
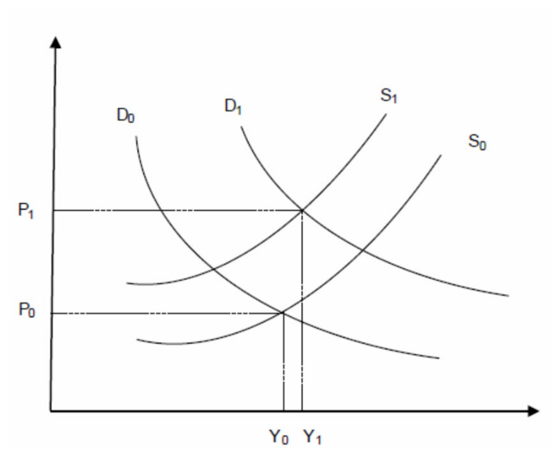


Figure 5b. Demand Shock and Rigid Supply



9. **Both types of supply constraints—disruptions and rigidities—dampen the responsiveness of output to demand and boost prices, but require somewhat different policy remedies.** Where bottlenecks result from the interaction of strong demand and rigid supply as in Figure 5a, only a softening in demand could alleviate the price pressures in the short run. Actions to boost supply above the pre-pandemic trend would also help, but they would likely take time to implement and bear fruit. In the case of disruptions as in Figure 5b, actions to help supply in the short run—for instance measures helping

people to return to work and meet the requirements of the newly available jobs, or adding to existing workers by easing immigration requirements and facilitating cross-border labor mobility via standardizing health certifications—could dampen price pressures relatively quickly and reduce the need for containing demand to avert an upward shift in inflation expectations.

IS IT HIGH DEMAND OR CONSTRAINED SUPPLY?

10. A sign-restricted Vector Auto Regression (SVAR) approach is used to quantify the contribution of supply and demand shocks to manufacturing production and the producer price inflation of manufactured goods (manufacturing PPI inflation, henceforth). The identification assumption is that demand shocks induce output and prices to move in the same direction, whereas supply shocks lead them to move in opposite directions:[5] [6]

$$\begin{pmatrix} IP_t \\ PPI_t \end{pmatrix} = \begin{pmatrix} + & - \\ + & + \end{pmatrix} \times \begin{pmatrix} demand\ shock_t \\ supply\ shock_t \end{pmatrix}$$

The index *t* is time in months. Manufacturing output (the manufacturing component of the Industrial Production index) is converted to a log-linearly detrended variable and used as the output measure. The price measure is the growth (annualized, in log points) of the manufacturing PPI during the last 3 months up to month *t* relative to the previous 3 months.[7] All variables are in monthly frequency, seasonally adjusted, and the sample period is January 2001 to September 2021. The sample includes the euro area, Germany, France, Italy, Spain, the United Kingdom, United States, Japan, Czechia, Mexico, and Turkey.

[5] Kilian, Nomikos, and Zhou (2018) and Goldman Sachs (2021) estimate sign-restricted VAR models to identify supply and demand shocks. Goldman Sachs applies the model to PMI new orders and delivery times, instead of manufacturing production and nonenergy producer prices as we do here.

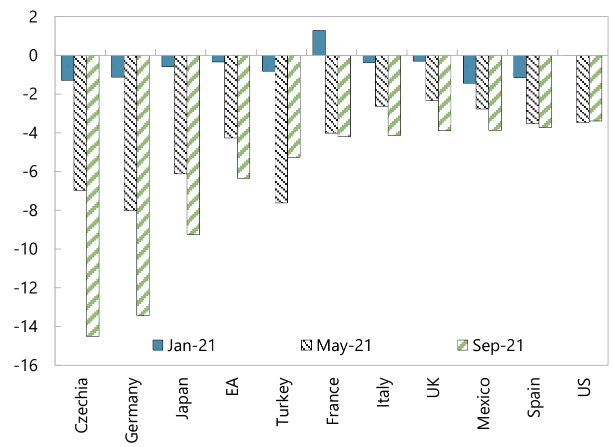
[6] IMF (2021) examines the impact of supply and demand shocks on output using two methods. In the first, it estimates a sign restricted VAR using PMI survey data on new orders (or output) and supplier delivery times, then relates the estimated supply and demand shocks to IP and GDP. In the second, the authors use the IMF's Flexible Suite of Global Models to back out the demand and supply shocks underlying GDP and core CPI movements.

[7] PPI inflation is calculated as $\pi_t^{PPI} = 400 * [\ln(PPI_t + PPI_{t-1} + PPI_{t-2}) - \ln(PPI_{t-3} + PPI_{t-4} + PPI_{t-5})]$. Using this three-monthly inflation measure helps smooth the noise in monthly data and avoid the strong base effects present in a twelve-monthly measure. To check robustness, we also estimate the model with month-on-month and 12-month inflation rates. Although the IRFs do change shape with the alternative inflation measures (since the sign restrictions are imposed on different compositions on months in each of them), the estimated impacts of supply shocks on output and inflation during 2021 do not change significantly.

11. **We find that, during 2021, the boost to output from higher demand has been largely, or in some cases more than, offset by supply shocks.** Estimated supply shocks are predominantly negative for the years before the pandemic, meaning that they supported output and held down prices (the historical decompositions of manufacturing output by country are shown in Figure A2.1 in the Annex; Figure 7 shows the decomposition for the euro area).[8] During the pandemic, however, months in which supply shocks are positive have been very common. Consistent with a deepening of supply disruptions in the automotive sector, Czechia, Germany, and Japan are estimated to have large cumulative supply shocks through the fall of 2021. Figure 6 shows that the manufacturing component of IP in September 2021 would have been about 14, 13, and 10 percent higher in those countries, respectively, without the supply shocks of 2021.[9] In the euro area, output in the absence of supply shocks would have been about five percent higher than trend in the Fall of 2021 due to the cumulative effect of demand shocks, instead it was about a percentage point lower due to a six percent drag from supply shocks (Figure 7, left).

Figure 6. Bivariate SVAR: Impact of Supply Shock on Manufacturing IP, Jan, May, and Sep 2021

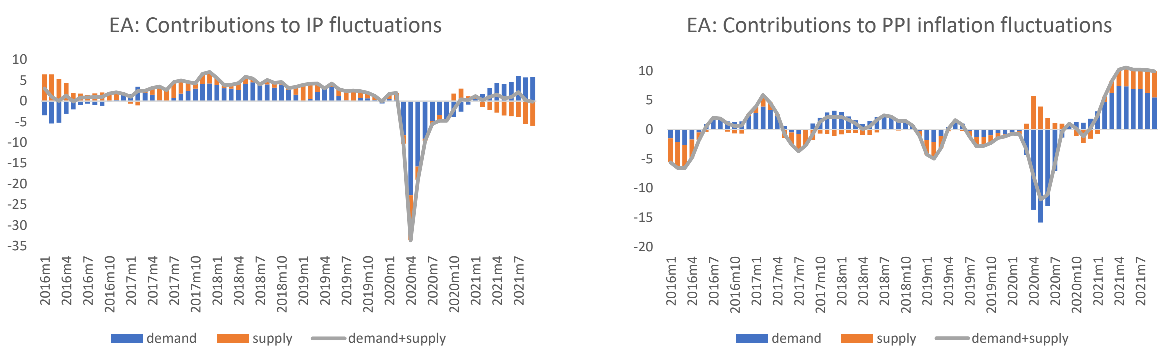
(percentage points)



Source: IMF staff calculations.

Notes: The values shown in bars are the impacts of the 2021 supply shocks on manufacturing IP in selected months.

Figure 7. Supply-Demand Decomposition of Manufacturing IP and PPI, 2016-2021



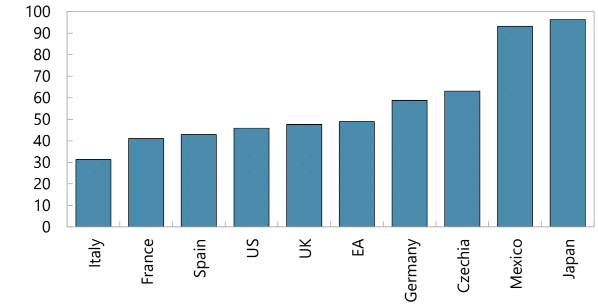
Source: IMF staff calculations.

[8] The historical decompositions split the dependent variables manufacturing IP and PPI into two components: one reflecting the cumulative effect of all past supply shocks, and another component reflecting the cumulative effects of all past demand shocks.

[9] The bars in Figure 6 capture the cumulative effects of the supply shocks of 2021 only (that is, abstracting from the shocks of 2020 and earlier years), as the supply disruptions we want to focus on occurred in 2021.

12. Supply shocks have also boosted inflation. Manufacturing PPI inflation in the euro area rose to 12.5 percent in 2021Q3 from an average of 1.8 percent in 2017–19. We estimate that close to half of that upward swing came from the change in the supply shock component, which had mostly exerted downward pressure on manufactured-goods prices in the pre-pandemic years. The share attributable to supply shocks varies across individual countries; it is estimated at about half for the euro area, 60 percent for Germany and 45–50 percent in the United States and the United Kingdom, and about 40 percent for France and Italy (Figure 8). Higher demand contributed the bulk of the remaining increase in manufacturing PPI inflation.[10]

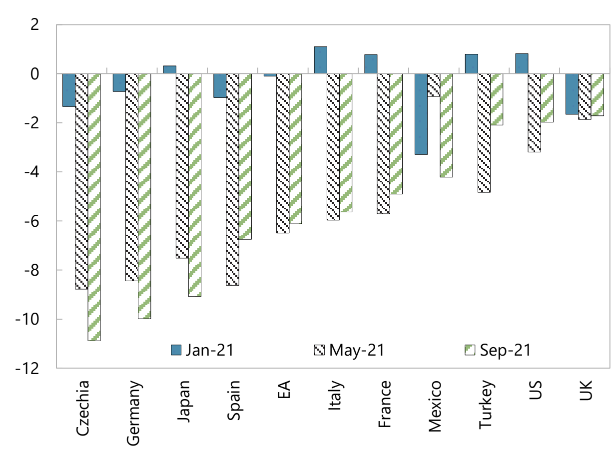
Figure 8. Supply-shock Contribution to the Change in Manufacturing PPI Inflation (2021 September relative to 2017-19)



Notes: The bars show how much of the change in inflation between 2017-19 and September 2021 can attributed to the shift in supply shocks (given by the ratio of (i) the supply-shock impact on PPI inflation in September 2021 relative to the supply shock impact in 2017-19 to (ii) the difference between manufacturing PPI inflation in September 2021 and average manufacturing PPI inflation in 2017-19, where all inflation rates are quarter-on-quarter and annualized).

13. Adding the PMI suppliers' delivery time as the third variable in the SVAR does not significantly alter the estimated shocks for 2021. The bivariate SVAR approach identifies the contraction of manufacturing output during the spring of 2020 as largely a result of a demand shock because manufacturing PPI inflation also plunged during that period. Though the interpretation of shocks during such a unique period is difficult, we add PMI suppliers' delivery time as the third variable to the SVAR to perform a robustness check. We restrict signs by assuming that a demand shock has a positive effect on manufacturing IP, manufacturing PPI inflation, and delivery times, while a supply shock has a negative effect on IP and a positive effect on inflation and delivery times (a third shock is left unspecified). With the three-variable SVAR, we find a larger role for supply shocks during the first half of 2020 relative to the bivariable SVAR, consistent with the rise in delivery times during the initial 2020 lockdowns. However, the

Figure 9. Three variable SVAR: Impact of Supply Shock on Manufacturing IP, Jan, May, and Sep 2021
(percentage points)



Source: IMF staff calculations.
Notes: The values shown in bars are the impacts of the 2021 supply shocks on manufacturing IP in selected months.

[10] The decomposition exercise matches 90–95 percent of the total change in inflation, leaving a small unexplained residual. Hence, the portion explained by demand is not exactly one minus the fraction explained by supply but instead a few percentage points less.

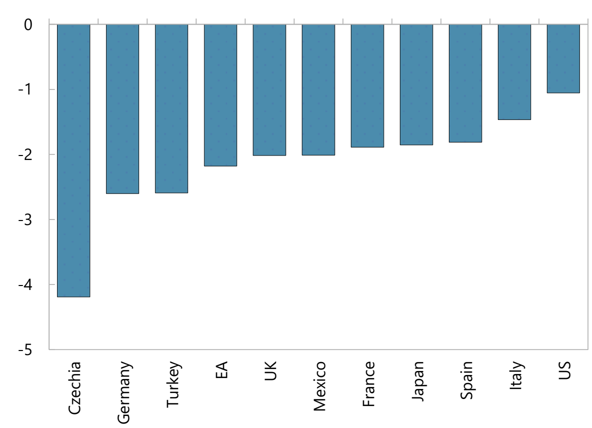
supply shocks during 2021 are estimated to be broadly comparable to those estimated using the bivariate SVAR (Figure 9). The drag on manufacturing output from supply shocks in this exercise is about 12 percent for Czechia and 10 percent for Germany and Japan, slightly smaller than in the bivariate SVAR. The same is true for the United States and the United Kingdom (about -2 percent as compared with -3 percent in the bivariate SVAR). By contrast, the estimated supply-side drags are larger for Italy and Spain in the three-variable SVAR than the bivariate one. The proportion of the demand and supply contributions to manufacturing PPI inflation are broadly similar in the three-variable and bivariate SVAR exercises, but the three-variable SVAR achieves a weaker fit than the bivariate case, leaving a larger fraction of inflation unexplained.

14. As an additional check, we use a quadratic rather than a linear trend in detrending manufacturing output. The quadratic trend provides a better fit for some countries, results are overall similar, and in some cases like Germany and Spain the supply-demand decomposition for manufacturing output for 2021 in this exercise seems more consistent with those for other countries (indicating a combination of demand and supply shocks that, respectively, increase and decrease manufacturing output; see Annex Figure A2.2).

15. We next translate the supply-side impacts we estimate for IP into those for real GDP. We use the simple historical correlation between manufacturing IP and GDP to get a rough estimate of the impact of the manufacturing supply-shocks on 2021 GDP.[11] The estimated impacts are large, varying from a setback of one in the case of the United States to about -2.5 percent in Germany and Turkey. The impact is about -4 percent in the case of Czechia (Figure 10).

Figure 10. Impact of Supply Shocks on 2021 GDP

(Percent relative to a counterfactual with no supply shocks in 2021)



Source: IMF staff calculations.
Notes: The calculation method is described in footnote 11.

[11] For this exercise, we first calculate the impact of supply shocks on manufacturing IP in 2021 by feeding the estimated supply shocks of 2021 through the impulse response function of supply shocks on manufacturing output (left most column of Figure A2.4). We then use the historical correlation between manufacturing IP and GDP to calculate a rough GDP impact. IMF (2021) uses inter-country input-output tables to determine the impact of the changes in manufacturing output on nonmanufacturing output within the same country as well as in other countries, then summing the domestic and foreign impacts for each country. The IP to GDP elasticities obtained that way are broadly comparable to those from the simple correlation method we employ here.

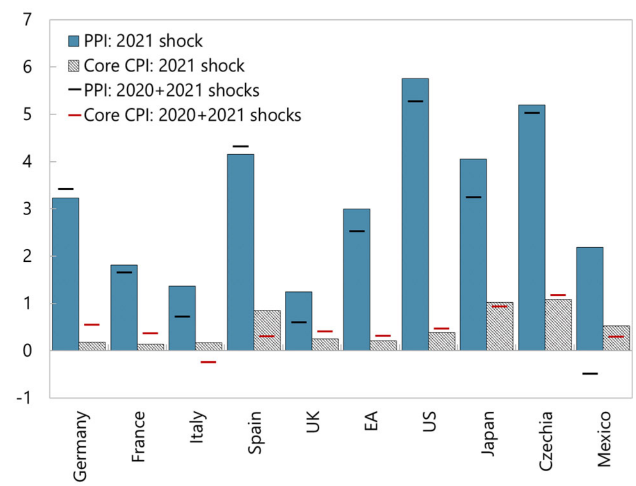
16. Finally, we look at the impact of the estimated supply and demand shocks on core CPI inflation. We estimate a local projection model, using the following specification:

$$\pi_{t+h}^{CPI} = \beta_h^d * demand_t + \beta_h^s * supply_t + \delta^h X_t + \varepsilon_t^h$$

where π_{t+h}^{CPI} is core CPI inflation (calculated in an analogous way to PPI inflation – see footnote 9) and $demand_t$ and $supply_t$ are the demand and supply shocks derived from the bivariate SVAR on manufacturing output and nonenergy PPI inflation. The estimated values of $\{\beta_h^d\}_h$ and $\{\beta_h^s\}_h$ underpin the impulse-response functions (IRFs) of interest, which are displayed in Annex 2 (Figures A2.3 and A2.4) together with the IRFs for nonenergy PPI inflation obtained from the SVAR.[12]

17. The supply and demand shocks driving manufacturing PPI inflation have a measurable but relatively small pass through to core CPI inflation. The peak impact of a "one-standard deviation" demand shock on PPI inflation is typically in the range of 1.5–2.0 percentage points. Given that we calculate inflation over a three-month rolling window, the fact that the IRFs peak about 3 months after the shock indicates that monthly inflation is highest on impact and then declines. Meanwhile, the impact of the same shock on core CPI is smaller, mostly peaking in the 0.20–0.30 percentage point range. Turning to supply shocks, the impacts on PPI inflation are smaller (but with a large amount of variation) than for demand shocks, and the pass through to core CPI is again partial. As goods make up only a subset of the CPI basket (typically around 30–40 percent) and since goods prices in the CPI include retailer margins, it is not surprising that the shocks driving manufacturing PPI have relatively muted effects on the overall core CPI index.

Figure 11. Impact of Supply Shocks on PPI and Core CPI Inflation (on average during Jan-Sep 2021)



Source: IMF staff calculations.
Notes: The values shown in bars are the impacts of the 2021 supply shocks on PPI and core CPI inflation during 2021; the values shown in lines are the cumulated impact of the 2020 and 2021 supply shocks. The values are the simple averages of the estimated impacts for the nine months between January 2021 and September 2021. The impacts are calculated using the estimated IRFs (shown in Annex 2).

[12] The SVAR decomposes movements in manufacturing PPI and output into components driven by demand and supply shocks, so by design the shocks can "explain" almost all of the variation in manufacturing IP and PPI. By contrast, the local projection method allows us to trace out the impact of the manufacturing supply and demand shocks on core CPI; it is not designed to match all its variation as in a decomposition exercise.

18. **The estimated impact of the supply shocks on core CPI inflation in 2021 varies across countries** (Figure 11). The cumulative impact of about 0.5 percentage point in Germany for the first three quarters of 2021 is close to the roughly 1.3 percentage points increase in core inflation in 2021 relative to its average over 2017–19, after removing the near 1 percentage point increase in core inflation in 2021 coming from the reversal of the VAT cut. By contrast, in the United States, the roughly 0.4 percentage point estimated impact of the manufacturing supply shock is a small fraction of the actual increase in core CPI inflation of about 2.5 percentage points over the same period. These differences likely reflect the fact that much of the difference in core CPI dynamics across countries reflects the variation in demand-supply imbalances in the service sectors, in addition to the variation in the impacts of the manufacturing supply shocks that we study here.

19. **The bottom line of this analysis is that supply shocks had large impacts on activity and inflation in 2021, though demand also explains about close to half of the PPI inflation increase:** (i) Supply shocks have been a major drag on manufacturing output and GDP in many countries; (ii) in many countries close to half of the rise in PPI inflation between 2017–19 and 2021Q3 came from supply shocks (in some countries like Germany and Japan the share is a bit higher); and (iii) the pass through of supply shocks to core CPI inflation is modest, but can nonetheless explain much of the rise in core CPI inflation relative to pre-pandemic averages in some countries. Nonetheless, the estimates leave a sizable role for demand in pushing up inflation.

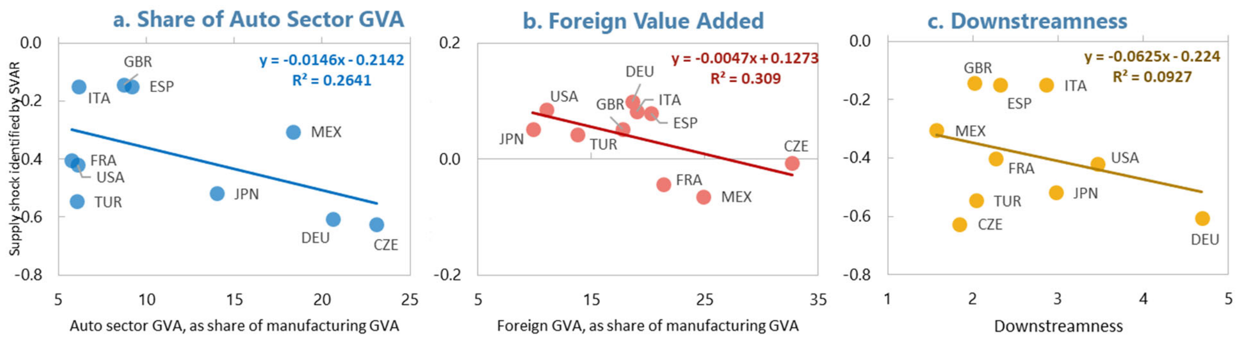
DRIVERS OF BOTTLENECKS

20. **This section examines the drivers of the supply shocks estimated in the previous section.** The key possible drivers are the impact of shutdowns at home and abroad (propagating through global supply chains) and labor shortages. These two factors are inter-independent, as both are ultimately driven by infection waves.

21. **The extent of supply problems has been diverse across countries and sectors.** For instance, delivery times have increased more in advanced economies than in emerging markets. Within advanced economies, manufacturing production has weakened during much of 2021 in Germany and in September–October in Japan, while continuing to recover in the United Kingdom and Spain. One reason for this diversity is likely to be the differing composition of manufacturing across countries, since some subsectors could be more vulnerable to disruptions than others. For instance, the auto and machinery sectors suffered severe production declines after 2021Q2 when the shutdowns to contain the Delta-variant of the virus started curtailing semiconductor production in Asia—and countries with large auto sectors have correspondingly suffered greater supply shocks (Figure 12a). Likewise, disruptions were larger in countries with higher shares of foreign value added in gross domestic manufacturing output

(Figure 12b), or where the manufacturing sector operates in the downstream segments of global value chains and is hence vulnerable to shutdowns that hinder upstream production (Figure 12c).[13]

Figure 12. Impact of Shutdowns: Country Diversity
(average from 2020 Jan to 2021 Sep)



Sources: Haver Analytics, OECD, and IMF staff calculations.
Note: Panels show the SVAR identified supply shocks in the previous section and country characteristics—share of auto sector GVA and foreign GVA, as share of total manufacturing GVA, and downstreamness of manufacturing sector (Antràs and Chor 2018). The supply shocks in the middle panel are the residual obtained after regressing supply shocks on domestic shutdowns.

Sectoral diversity

22. Sectors that rely more heavily on differentiated intermediate inputs are likely to experience more severe constraints in the aftermath of shutdowns.[14] Differentiated inputs (such as semiconductors) tend to require more specialized production processes and their supply is likely to be relatively rigid in the short run (we zoom into the scarcity of semiconductors in section six). To test this hypothesis, we use a monthly country-sector panel dataset from 21 European economies. The specification links sectoral output dynamics to shutdowns, allowing for the impact of shutdowns on a sector to depend on its "differentiated inputs usage":

$$IP_{ist} = \alpha IP_{ist-1} + \beta_1 Shutdown_{ist} + \beta_2 Share_{is}^{diff} \cdot Shutdown_{ist} + \epsilon_{ist},$$

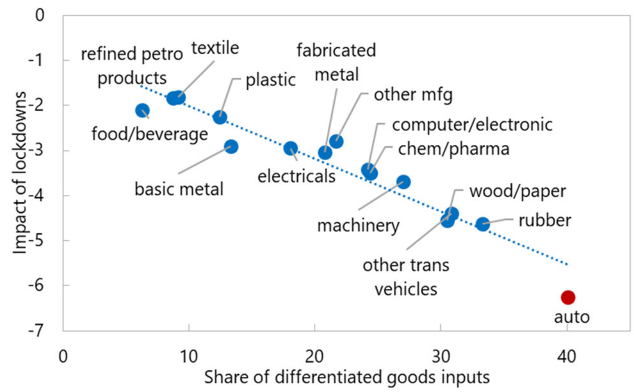
[13] On average, manufacturing in Asia tends to be in the upstream part of global value chains, America is typically downstream, and Europe usually locates in between (Antràs and Chor 2018).

[14] Intermediate inputs vary in their degree of substitutability. Firms can switch suppliers relatively easily if needed for homogeneous goods such as fuel or other primary commodities. By contrast, for differentiated goods such as microchips customized to firm-specific operating platforms and products, replacing a supplier takes time and may significantly add to costs (Barrot and Sauvagnat, 2016). Moreover, the supply of differentiated, specialized, intermediate inputs could be rigid in the short run, as has been the case for semiconductors (Section six).

where IP_{ist} is the output of sector *s* in country *i* in period *t*, in deviation from output in the same month of 2019. To calculate $Share_{is}^{diff}$, the degree of country *i* sector *s*' differentiated input usage, we divide all sectors into two groups: those producing homogeneous goods and those producing differentiated goods, based on the Rauch (1999 classification). We then calculate the share of inputs into sector *s* in country *i* from differentiated-goods-producing sectors, using input-output tables. To calculate $Shutdown_{ist}$, we first interact measures of sectors' teleworkability (as in Dingel and Neiman, 2020) with measures of shutdown stringency in the domestic economy to create shutdown series specific to all the country-sector pairs in the dataset. Then $Shutdown_{ist}$ for sector *s* of country *i* in month *t* is given by the average of the shutdown series of all the domestic and foreign input-providing sectors, weighted by the share of each input-providing country-sector pair into the output of sector *s* in country *i*. The regression results and detailed variable definitions are provided in Annex 3.

Figure 13. Impact of Shutdowns: The Role of Differentiated Goods Inputs

(average from 2020 Jan to 2021 Aug, percent deviation from 2019)



Sources: Haver Analytics, OECD, Rauch (1999), and IMF staff calculations.
Note: This panel shows the impact of domestic and foreign supplier countries' shutdowns on sectoral production, in relation with the sector's share of inputs from differentiated-goods-producing sectors. The differentiated-goods-producing sectors are those with half of its products are differentiated goods (by Rauch classification). See Annex 3 for estimation details.

23. The estimates confirm that shutdowns have disrupted production more severely in sectors that are more reliant on highly differentiated intermediate inputs, such as autos. Both variables—shutdowns and shutdowns interacted with the degree of differentiated-input usage—are statistically significant in the regression. The auto sector—which relies on differentiated inputs most heavily among all manufacturing subsectors—is predicted to have suffered three times more than the textile sector (the sector that is least reliant on differentiated inputs) from the shutdowns (Figure 13).

Drivers of Country-Level Supply Shocks

24. How well can shutdowns and domestic labor shortages explain the supply shocks estimated using SVARs in the previous section? To answer this question, we build on the previous analysis in this section and estimate the following specification using monthly data for 8 countries:

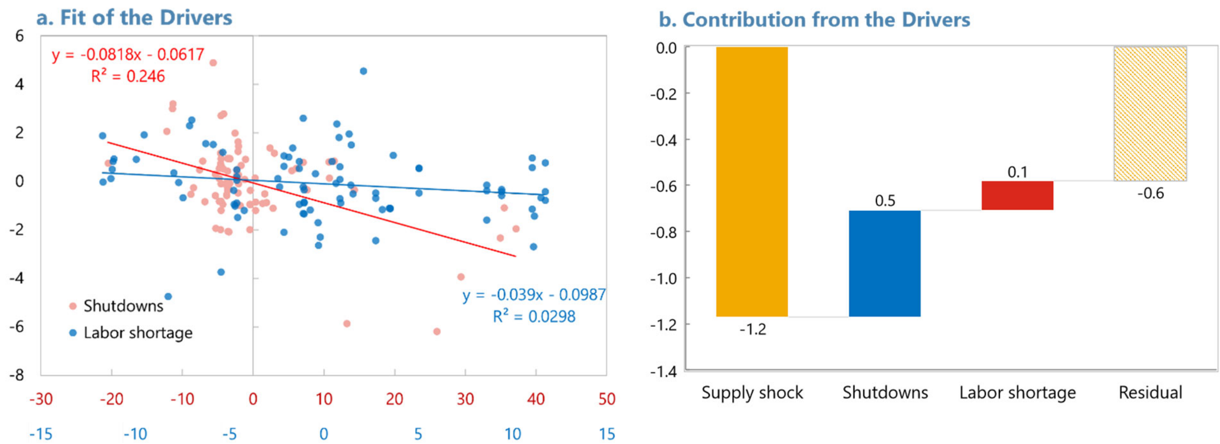
$$Shock_{it}^{supply} = \beta_1 Share_{it}^{labor\ shortage} + \beta_2 Shutdown_{it} + \beta_3 Exposure_i \cdot Shutdown_{it} + \alpha_i + \epsilon_{it}$$

The country-level $Shutdown_{it}$ variable is constructed similarly to that at the country-sector-level, averaging the home and foreign countries' shutdowns weighted by the share of country *j*'s output used in the total output of country *i*. Given the diversity in sectoral impacts documented in the previous subsection, we allow the marginal impact of shutdowns to vary based on a country's exposure to shutdowns, proxied by the weight of the auto sector, dependence on foreign value added, and the degree of "downstreamness" in global value chains. To measure labor shortages, we use the share of firms in establishment surveys reporting their production capacity to be constrained by labor scarcity.[15]

25. The results confirm the role of shutdowns and labor shortages in dragging down supply (Figure 14). Overall, the shutdowns and labor scarcity can account for about half of the variation in supply shocks between 2021–20 and 2019, with shutdowns contributing 40 percent and labor shortages contributing another 10 percent (Figure 14b). Some of the rest of the variation could potentially be attributed to logistical infrastructure bottlenecks and natural events disrupting production in 2020-21 (see the discussion of the latter in the section on the semiconductor sector). The limited role of labor shortages in driving manufacturing supply shocks can appear surprising amidst growing attention to the issue and weakened labor force participation in some economies relative to before the pandemic. It is possible that labor shortages are most severe in the service sectors (instead of the manufacturing sectors examined here), where potential workers are more concerned about contact-intensity and health risks, constrained by occupation licenses, and discouraged by low pay.

Figure 14. Drivers of Supply Shocks

(2019 Jan to 2021 Sep)



Sources: Confederation of British Industry, European Commission, Haver Analytics, OECD, U.S. Census, and IMF staff calculations.
Note: Panel a shows the relationship between supply shocks and labor shortage (in blue), residualized from shutdowns; and the relationship between supply shocks and shutdowns (in red), residualized from labor shortage. Panel b shows the contribution of shutdowns and labor shortage to the average decrease in supply shocks in 2020/21, relative to 2019. The estimates are based on regressions including foreign value-added share, and the ones including auto share or downstreamness show similar results.

[15] This measure should be less affected by reverse causality from supply shocks compared with labor market outcomes such as employment.

SEMICONDUCTOR SHORTAGES DURING THE PANDEMIC: A PERFECT STORM

26. The market for semiconductors has suffered significant disruptions since the onset of the pandemic.[16] Factors related and unrelated to the pandemic have increased demand and reduced supply in the market, leading to shortages and taking a particularly large toll on vehicle production.

- **Demand:** The demand for semiconductors had already been affected by geopolitical tensions prior to the pandemic, particularly those between the U.S. and China. With semiconductors increasingly becoming a strategic resource, some countries had been seeking to increase their resiliency by partially renationalizing production and stockpiling inventories. The pandemic has tightened the market further, by shifting consumer demand toward semiconductor-intensive durable goods. Initially, with the switch to work - and study-from-home, the demand for IT devices boomed. The demand for vehicles (which also increasingly incorporate semiconductors) also began to pick up in the second half of 2020 (after plunging at the onset of the crisis), adding to the competition for semiconductors. The shortage has been further aggravated by firms multiplying their orders beyond their immediate needs, in a bid to hedge against a more persistent scarcity.[17] While the push for renationalization will likely increase supply, this will take several years to materialize. In the meanwhile, geopolitical tensions will sustain a drive to build inventories.
- **Supply:** Containment measures against the spread of the COVID-19, including localized lockdowns and border closures, have affected factory production and disrupted the functioning of distribution networks, including for semiconductors. At the same time, natural events unrelated to the pandemic (drought conditions in Taiwan Province of China since 2020, a spell of extremely cold weather in Texas in February 2021, a fire in a Japanese semiconductor factory in March 2021, and floods at Chinese ports in August 2021) have further disrupted production.

27. As a result of strong demand and weak supply, quantities traded have surged, aggregate prices have increased moderately, and some pockets of the market are reporting acute shortages. As shown in Figure 15, in September 2021 the global trade in semiconductors was 19 percent above its long-term trend, while the exports of Taiwan Province of China, a major player in the industry, were 27 percent above trend. Furthermore, capacity utilization in the U.S. has been well above historical averages (but at similar levels as in 2018[18]). Despite these significant increases in global semiconductor

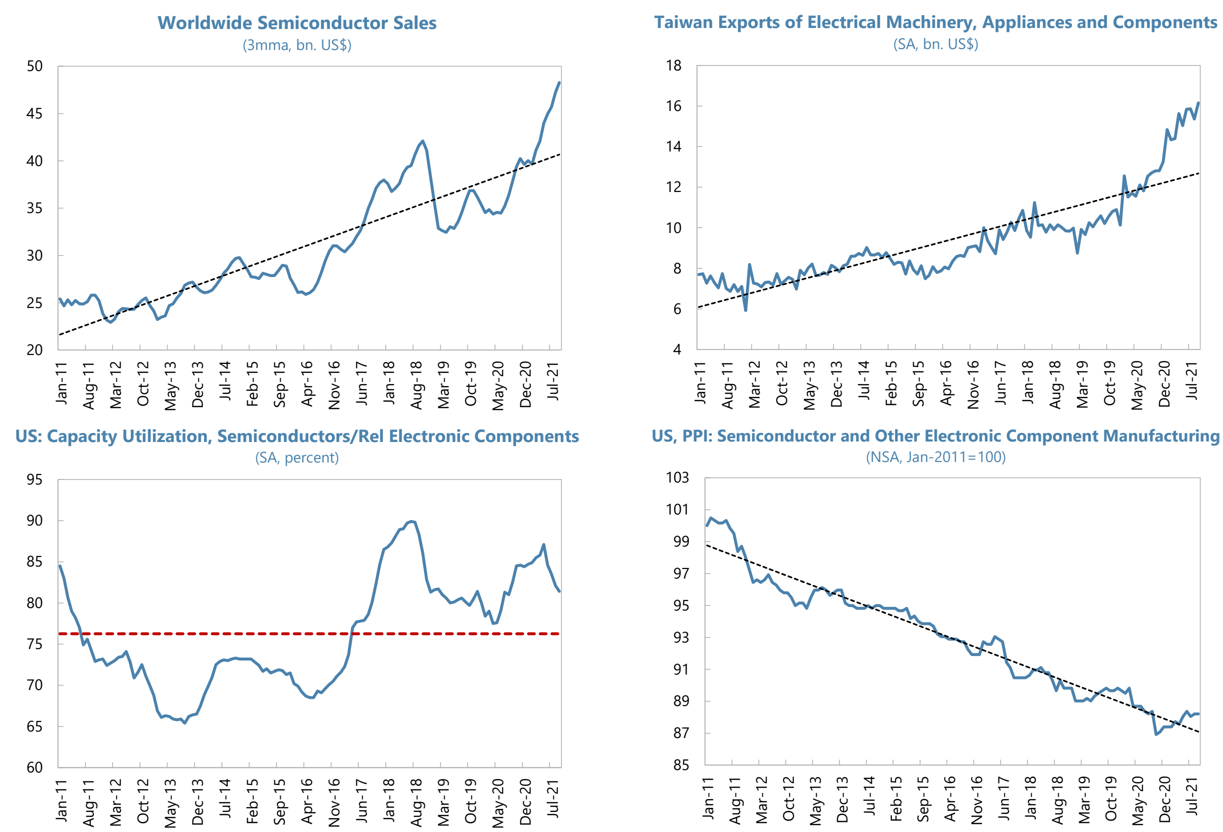
[16] Annex 4 provides details on the structure of the industry and production stages.

[17] See, for example, Financial Times (2021).

[18] Capacity utilization in 2018 might have been unusually high because of the sanctions imposed on China. Ahead of U.S. export controls taking effect, some Chinese firms appear to have stockpiled semiconductors, leading to a sharp increase in production followed by a slump.

trade and capacity utilization at production facilities, some user-industries are reporting semiconductor shortages, particularly the auto sector. Meanwhile, the U.S. PPI subindex for manufacturing of semiconductor and other electronic components is only 1 percent above its longer-term trend. Discussions with experts suggest two possible explanations for the small movement in prices despite acute shortages: first, the supply weakness might be specific to some pockets of the industry (particularly the production of more dated, “legacy” chips for which investment has been weaker in recent years) and price hikes in those pockets have a small impact on aggregate indices; and second, chips are generally not traded in spot markets as commodities but rather through long-term contracts with fixed prices. With prices mostly unchanged in the short run, the market must necessarily adjust via quantity rationing; anecdotal evidence suggests that automakers in particular cancelled chip orders early in the pandemic (when the demand for cars collapsed) and “lost their place in line” to other chip users like consumer electronics (which absorb most of the semiconductor output and are likely to be prioritized by suppliers).

Figure 15. Key Indicators for the Semiconductor Market



Sources: Federal Reserve Bank of St. Louis; Federal Reserve Board; Haver Analytics; Ministry of Finance, R.O.C.; Semiconductor Industry Association; and IMF staff calculations.

28. In the short term, shortages are expected to be resolved mainly through a normalization of supply and demand, but in the long run significant capacity expansion is expected. As the pandemic gradually loses its strength, demand is likely to partially shift back towards services, helping to ease the semiconductor shortage—although some of the rise in demand in goods might be permanent due to changes in consumer and work habits. An easing of containment measures and less frequent shutdowns, particularly in East Asia, would help normalize supply and allow factories to catch up with the backlog of orders associated with the Delta surge and the disasters of 2021. While some extra production capacity is being added in the short term by hiring more workers and incorporating more machinery into existing factories that have space available, more significant expansions of productive capacity will require building new foundries, which can take about 2 to 4 years. Major capital investments have been announced in 2021, totaling about $900bn (to be invested through 2030).[19] Plans to expand capacity in the long term reflect both government incentives to increase domestic production, and investors' expectations that part of the surge in demand will be permanent. Therefore, even as the industry is currently experiencing shortages, there is also a risk of excess supply in the long run.

29. The shortage of semiconductors has hit global vehicle production hard, with varied impacts across countries. Going into the pandemic, the auto industry was vulnerable to supply chain disruptions as it is reliant on differentiated intermediate inputs and largely operated under a just-in-time model with lean inventory buffers. While the pandemic-driven semiconductor shortages have had widespread effects on industrial output, the impact has been severe in the auto industry, where plants have suspended worker shifts or temporarily shut down due to insufficient stocks of chips. In September 2021, motor vehicle manufacturing in the U.S., Germany, and Japan was thus lower than its 2019 level by about 13, 33, and 40 percent, respectively, a larger shortfall relative to the one for overall industrial output. Discussions with industry experts suggest that European and North American automakers were generally more vulnerable than Japanese and Korean companies because they rely mostly on older chip technologies, for which shortages have been more acute. Furthermore, Japanese companies have tended to operate with a few months of inventories after the lessons learned from the 2011 Tohoku earthquake and tsunami. However, the higher stocks helped Japanese automakers delay, rather than completely avoid, production cuts amidst semiconductor shortages (Sheffi, 2021).

[19] See "Chip Shortage Update: To Get Worse Before It Gets Better", Fitch, 2021.

HOW SOON MIGHT SUPPLY BOTTLENECKS EASE?

30. Much of the supply constraints brought on by the pandemic are likely to prove transient, but some could take a long time to ease. As discussed in the previous two sections, shutdowns to contain the Delta-surge and several disasters disrupted production facilities and ports in various countries the spring and summer of 2021, hindering semiconductor and auto output in particular. Based on data compiled by the Susquehanna Financial Group, the lead times for semiconductors—a gap between when a semiconductor is ordered and when it is delivered—remained high at 25.7 weeks in January, largely unchanged from its peak the previous month and significantly higher than its range of 12-15 weeks in 2018-19. Without new virus surges or disasters, the backlogs caused by these setbacks would gradually clear up. Yet, with the rapid spread of the Omicron variant and the mobility restrictions introduced in response in many countries since December 2021, the outlook is uncertain, and disruptions may continue for some time. The impact of the pandemic on the labor market is also difficult to gauge. The pandemic has spurred health concerns and hesitancy among the unemployed to take up contact intensive jobs, led to a re-evaluation of work preferences, reduced the flows of migrant workers, and created skills mismatches by changing the composition of spending. Like for shutdowns, the path of labor supply will depend on the evolution of the pandemic. However, if sustained, preferences for reduced work hours would permanently lower effective labor supply.

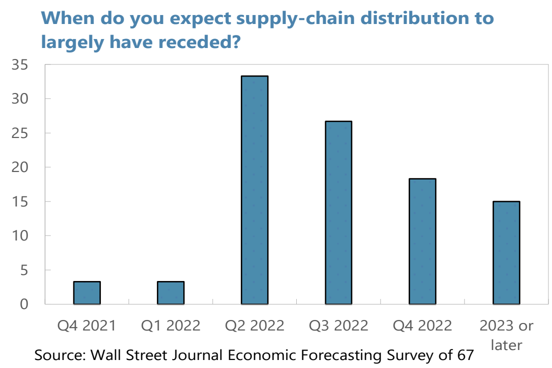
31. In conversations during November 2021, industry experts expected microchip shortages and logistical bottlenecks to fade by mid- and end-2022, respectively (Figure 16a).

- **Semiconductors.** According to key German automakers, absent renewed lockdowns, or idiosyncratic shocks (e.g., accidents affecting microchip plants), order backlogs should decline considerably during the first half 2022 as existing semiconductor plants work at capacity (moreover, their capacity would increase to some extent by new investments). However, a further expansion of supply—to meet the structural increases in demand from a shift in preferences toward electric vehicles—would take longer, awaiting new semiconductor factories to come online (which takes 2–4 years on average).

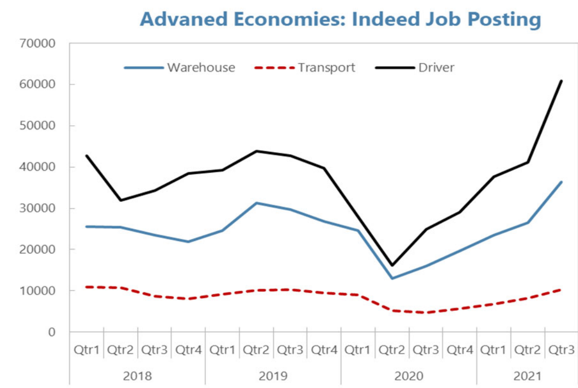
- **Logistical bottlenecks.** Both PMIs and shipping rates appear to suggest some easing—or at least some stabilization—of the bottlenecks, but supply conditions remain unfavorable from a historical perspective. Shipping prices should gradually moderate as the demand for goods normalizes and capacity in the shipping market expands (since late-2020, the number of containerships on order have almost tripled). Prices of long-term shipping rate contracts, which cover a substantial part of the container market, have risen less than the spot rates, suggesting that market participants do not expect the rise in spot-prices to be permanent. However, supply disruptions themselves slow the construction of new ships and containers. Moreover, the path of the pandemic remains uncertain, and renewed waves could delay a normalization. Sea transport companies highlight continued challenges in sorting out the problems surrounding dislocated containers/vessels and in expanding capacity—e.g., building new containers—indicating that it will take longer for shipping congestion to ease (in the second half of 2022 or in 2023). To mitigate bottlenecks, the land transportation sector has been increasing job postings, especially for drivers (Figure 16b).

Figure 16. Market Expectations on Supply Normalization and Transport Job Postings

a. Market's Views on the Timing of Supply Normalization **b. Job Postings in the Transport Sector**

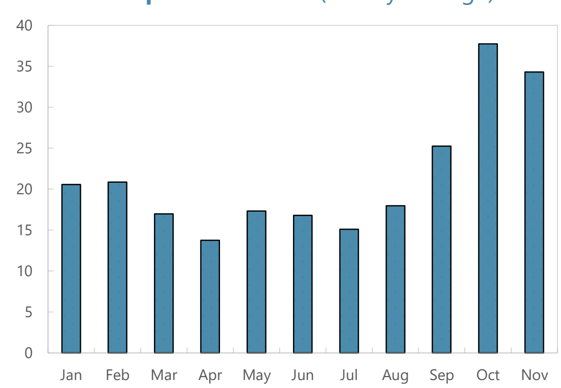


Source: Wall Street Journal Economic Forecasting Survey of 67 economists, Oct 8-12, 2021.



32. Findings of a news-search exercise on when the bottlenecks will fade are consistent with the expectations of industry experts.[20] Using GDELT, a global news database, indices were calculated for online news citations using the terms "supply bottleneck," "supply issue," and "chip shortage," combined with terms related to the timing of easing. The first finding is that the frequency of terms referring to supply disruptions used on web news seems to have peaked (Figure 17). For microchips, most of the online news suggests that shortages will ease in 2022, rather than 2023 (Figure 18a). Within 2022, views are divided about half and half on whether the easing will be in the first or second half of the year (Figure 18b). A search for "supply shortage" or "supply issue," a broader concept than microchip shortages, suggests that broader bottlenecks are expected to fade in the second half of 2022.

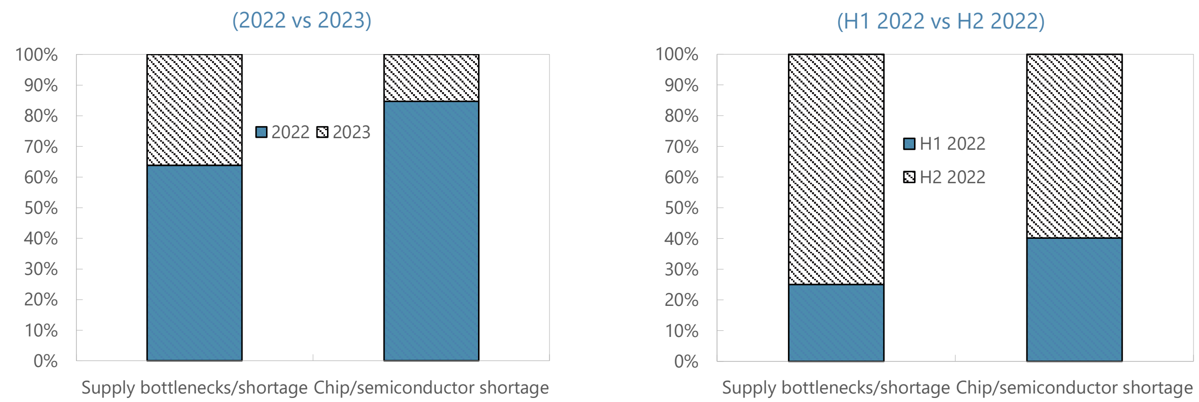
Figure 17. Frequency of Terms Related to Supply Disruptions in News (weekly average)



Sources: Google Trends and Fund staff calculations.
Note: The following terms are used for search: "delivery delays," "supply bottlenecks," "supply chain disruption," supply constraints," supply disruption."

[20]The exercise was conducted in early December 2021.

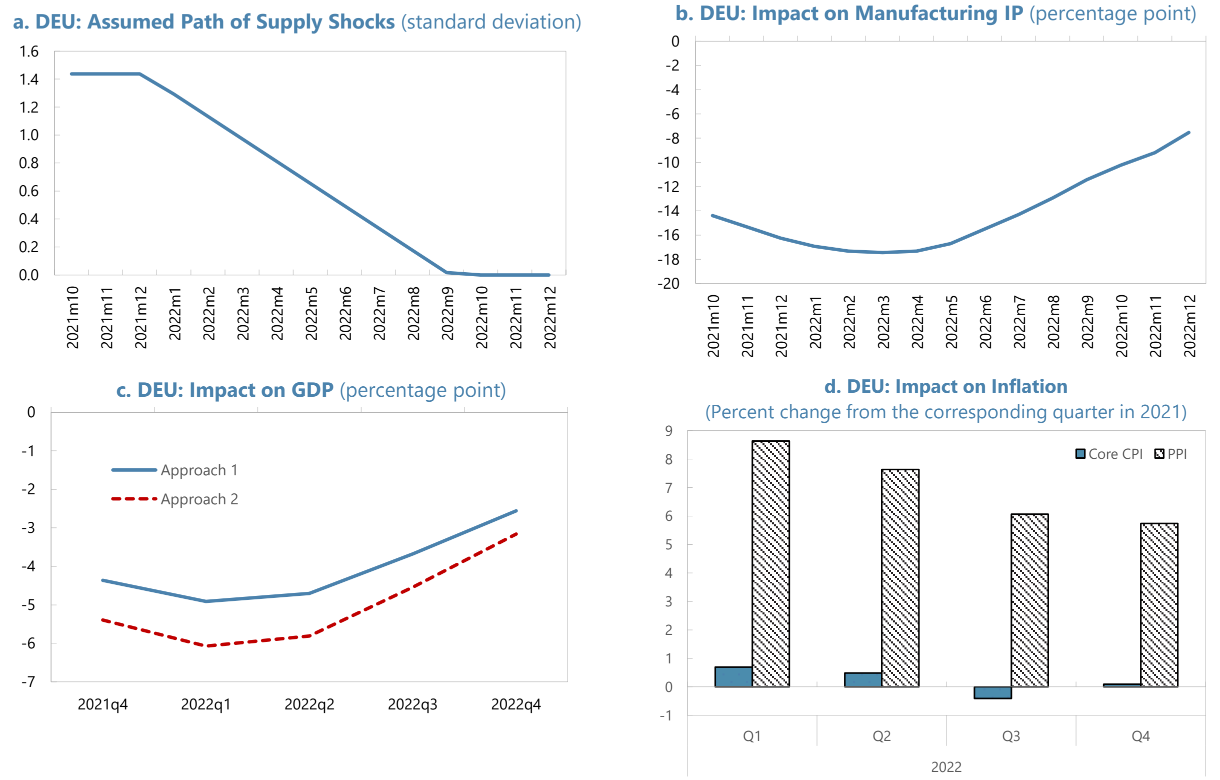
Figure 18. Online News: When Supply/Chip Shortage Eases



Sources: GDEL; and IMF staff calculations.

33. Assumptions on when the bottlenecks will fade can be incorporated into growth and inflation forecasts. The first step is to assume a path for future supply shocks. As an example, we assume that supply shocks will stay at their September 2021 level through the end of 2021, and then dissipate by September 2022, as depicted in Figure 19a. Second, the estimated Impulse Response Functions from the SVAR can be used to project the impact of the assumed 2021 supply shocks on manufacturing output and core PPI, as shown in Figures 19b and 19c. Given the transmission lags, the effects on these variables take couple of more quarters to ease than the underlying supply shocks themselves. Third, the projected impact on manufacturing output is transformed into a projected impact on GDP, either using: (i) the historical relationship between IP and GDP; or (ii) the input-output based method described in IMF (2021). Panel c in Figure 19 shows the results based on the historical relationship between IP and GDP: under the assumed path of shocks, in the fourth quarter of 2021, supply constraints would lower German GDP by 4 to 5 percent, and the drag would decline to around 2.2-3 percent by the fourth quarter of 2022. For manufacturing PPI inflation, the impact would go from about 7 percentage points in the last quarter of 2021 to about 9 percentage point in the first quarter of 2022 and decline to 6 percentage points in the final quarter of 2022. For core CPI inflation (Figure 19 panel d), the impact would be 0.7 percentage point in the first quarter of 2022, soften to 0.5 percentage point in 2022, and then turn negative in the third quarter of 2022 before approaching zero in the fourth quarter (Figure 19d). These impacts can be thought of as the impacts of the 2021 supply shocks relative to a baseline without sizable supply constraints, such as the Spring 2021 WEO forecasts.

Figure 19. Translating IP Impacts to GDP and Inflation Impacts



Source: IMF staff calculations.

TAKEAWAYS AND POLICY IMPLICATIONS

34. This paper seeks to quantify the impact supply constraints had on output and inflation in 2021. As the pandemic took hold, consumer demand shifted from services to manufactured goods. The reopening of economies initially boosted manufacturing output, but renewed lockdowns and shortages of intermediate inputs and labor caused the global manufacturing recovery to stall in 2021. Goods delivery times rose to record highs and prices of many goods rose rapidly. Core goods consumer price inflation also increased as a result, sparking a heated debate about the course of monetary policy. Designing the right policy responses will first require an understanding of the relative impacts of demand strength and supply constraints on inflation and output, and then gauging how persistent those shifts may be. We take a two-pronged approach in this paper: we first quantify the contributions of supply versus demand to fluctuations in manufacturing output and inflation in 2021 using an SVAR approach, and in a second step we investigate the extent to which transient factors such as shutdowns were responsible for the supply constraints.

35. **We find supply bottlenecks to have imposed a sizable drag on output.** During 2021, the estimated boost to output from the recovery in demand has been largely, or in some cases more than, offset by supply shocks. We estimate that the recovery in demand would have propelled euro-area manufacturing output about 5 percent above its underlying trend in the fall of 2021; absent a roughly 6 percent drag from supply constraints (the total effect left euro area manufacturing output slightly below its underlying trend in the fall of 2021). Based on the historical correlation between manufacturing and overall output, we estimate that euro area GDP would have been about 2 percent higher—close to about one year's worth of growth in normal pre-pandemic times for many European economies. The output drags were largest in countries where manufacturing firms operate at the downstream end of global value chains and are reliant on highly differentiated intermediate inputs. Key examples include countries with large automotive sectors, such as Germany and Czechia, where without the pandemic manufacturing output would have been higher by a staggering 13–14 percent in the fall of 2021.

36. **Supply constraints also played a significant role in fueling manufacturing price inflation in the euro area—but so too did strong demand.** The producer price inflation of manufactured goods in the euro area was about 10 percentage points higher relative to pre-pandemic times in the first three quarters of 2021. We estimate that supply shocks can explain about half of the increase in producer prices. The rest is mostly explained by higher demand. There was less impact from supply shortages on the part of consumer price inflation excluding energy and food prices. This core measure of inflation was only about 0.5 percentage points higher over the same period than it would otherwise have been without supply constraints in manufacturing. This smaller effect is not surprising because services make up more than half of the consumer price basket, and their prices are less sensitive than those of goods to manufacturing supply and demand shocks.

37. **Globally, up to 40 percent of the supply shocks can be traced to shutdowns, which should only have only transient effects.** The same is true of the severe weather and industrial accidents that hindered microchip output in 2021. Other drivers of supply constraints, such as labor shortages (which explain up to 10 percent of manufacturing supply constraints) and inadequate logistics infrastructure, could have more persistent effects on supply.

38. **The semiconductor market has suffered some of the most severe shortages, taking a toll on automobile production.** The disruptions resulted both from strong demand for electronic goods during the pandemic, and the rigid and or weakened supply of semiconductors due to shutdowns and weather effects. With much of the trading taking place with long-term contracts and fixed prices, the market adjusted through quantity rationing; anecdotal evidence suggests that automakers were not prioritized by suppliers under tight market conditions because they cancelled chip orders early in the pandemic when the demand for autos plummeted.

38. Pressures on inflation could persist. Fiscal support is waning, but the recovery of labor markets and incomes, not to mention a large stock of forced savings accumulated during the pandemic, may continue to bolster overall consumer demand. The shift in demand away from services towards goods could also persist as COVID-19 becomes an endemic disease. Late last year industry experts expected supply shortages for autos to largely dissipate by mid-2022 and broader bottlenecks by end-2022. Omicron has injected new uncertainty into the picture. Europe and China have imposed new restrictions and more disruptions could follow. All in all, supply disruptions will likely last for longer, possibly into 2023.

39. The first line of defense for policymakers is to tackle supply bottlenecks directly with regulatory measures wherever possible, for instance by fast-tracking the licensing of transport and logistics workers, temporarily easing restrictions on port operating hours, streamlining customs inspections, easing immigration rules to alleviate labor shortages, and mandating practices that limit the spread of the virus and protect the health of workers.

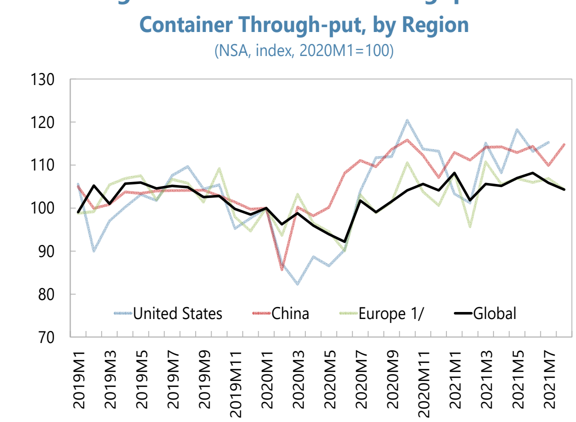
40. Fiscal policy measures should also be deployed actively to ease the bottlenecks and avoid permanent damage to potential output. Broad-based aggregate demand support at this juncture could intensify the bottlenecks and raise inflation with limited impact on output and employment. Support should instead be well targeted. For instance, it remains important to preserve the jobs that will be viable once the bottlenecks ease (for instance, the skills-intensive manufacturing jobs affected by shortages of intermediate inputs). Equally vital is to ensure a recovery in labor supply by removing current obstacles to and disincentives for work (by promoting the availability of reliable childcare and elder care during the pandemic, for example) and by helping workers get training for the newly needed skills.

41. The prospect of prolonged supply bottlenecks raises challenges for monetary policy—namely to sustain a still-incomplete recovery and ensure that output catches up with its pre-pandemic trend—without allowing wages and prices to spiral upwards. Key to managing this trade-off is to keep medium-term inflation expectations stable in the face of transient boosts to inflation, including from pandemic-driven supply disruptions and surging energy prices. Notwithstanding rapidly declining labor market slack in the euro area, based on recent data and historical precedent, wage growth is expected to be moderate, and inflation is projected to fall slightly below the European Central Bank's target once the pandemic fades. In general, to anchor expectations at target rates, it is critical that central bankers continue to communicate how they will react to inflation and other pertinent economic data, including movements in inflation expectations, and preserve flexibility to respond rapidly to any significant change in the medium-term inflation outlook. The more successful targeted regulatory and fiscal measures are in alleviating the supply bottlenecks, the less likely it is that policymakers would be forced to dampen aggregate demand and economic growth to contain inflation.

Annex 1: Determinants of Waiting Times in Ports

The global trade of goods increased sharply from the middle of 2020, straining logistics networks. Between September 2020 and September 2021, global container throughput—a measure of the number of vessels ports handle over time—averaged 6 percent above its 2019 level (Figure A1.1).[21] The demand for trucking and warehousing has also increased in many countries, notably in the U.S. and the Netherlands, a major gateway for goods into and out of Europe. The higher demand for transportation had to be accommodated with a mostly fixed stock of containers, ships, trucks, and storage facilities in the short run. In fact, though the number of containers in service has risen since late 2020, the effective supply of containers has been severely hampered by bouts of lockdowns and interrupted port operations, with many containers initially stranded off their usual routes. Industry experts estimate the effective stock of containers to be 10–15 percent below capacity (due to waiting times at ports). The result has been unprecedented congestion in some major ports and a six- to seven-fold increase in shipping costs.

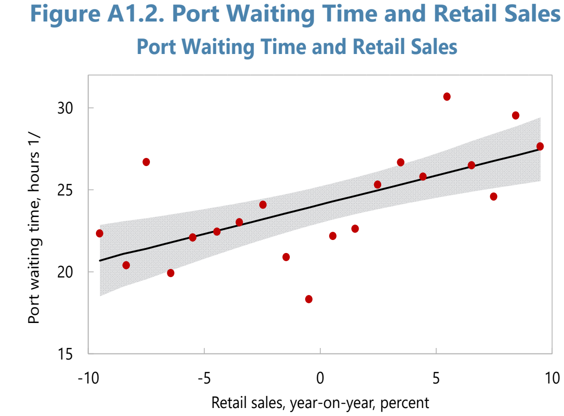
Figure A1.1. Container Throughput



Source: RWI; Bloomberg.
Notes: 1/ Europe includes the important continental European ports on the North Sea.

The strength of final demand and the stringency of containment measures can explain part of the diversity in port congestion. Countries with the highest growth in the demand for finished goods—proxied by growth in retail spending volumes—have also seen the most intense congestion in ports (Figure A1.2, based on the regression analysis described below). Containment measures have also contributed. For example, waiting times in Chinese ports went up during the summer of 2021, when two major ports

Figure A1.2. Port Waiting Time and Retail Sales



Sources: Marine Traffic; Cerdeiro, Komaromi, Liu and Saeed (2021); and IMF staff calculations.
Notes: 1/ Average number of hours container ships at Anchorage have waited to enter ports. Data is binned by intervals of 1 percentage point.

[21] The 6 percent increase refers to a seasonally- and working-day adjusted measure; Figure A1.1 shows unadjusted numbers.

were affected by containment measures.[22] Waiting times at ports have also increased the most in the United States. Based on anecdotal evidence, the quality of logistics infrastructure has contributed to these differences (North American spending on inland transport infrastructure has been below the OECD average during 1995–2016, based on International Transport Forum, 2018).

Analysis of port congestion

To assess the drivers of port congestion, the following regression is estimated:

$$pwt_{c,t} = \alpha_c + \alpha_t + \beta pwt_{c,t-1} + \gamma rs_{c,t} + \phi cm_{c,t} + \epsilon_{ct} \quad (1)$$

where $pwt_{c,t}$ is the average number of hours container ships at anchorage have waiting in country c in month t, $rs_{c,t}$ is the year-to-year growth in retail sales (volumes), and $cm_{c,t}$ is the strength of containment measures. The measures are set to zero before 2020. Country (α_c) and time (α_t) fixed effects are also included. Port waiting times are from Marine Traffic using the method from Cerdeiro, Komaromi, Liu and Saeed (2021).[23] Retail sales (volumes) are downloaded from Haver Analytics, and containment measures stem from Hale and others (2021). Data for 19 countries[24] is included during the period 2015M1–2021M10. Driscoll-Kraay standard errors are reported in parenthesis. As the number of time periods is well above 30 the Nickell bias is unlikely to be a problem (Judson and Owen, 1999).
The results of the regressions are reported in Table 1. Columns 1–2 report results when fixed effects are only included at the country level. Column 1 does not include a lagged dependent variable, while column 2 does. In columns 3–4 both time and country fixed effects are included, again without (column 3) and with (column 4) a lagged dependent variable.

A positive and significant relationship between retail sales and average port waiting time is found across all specifications. The coefficient varies from 0.12 to 0.31, suggesting that a 1 percentage point increase in retail sales (volumes) is associated with an increase in port waiting time for ships of 0.12 to 0.30 hours. Containment measures are also found to be associated with longer port waiting time, but the relationship is only significant in the specifications without time fixed effects. The share of variation explained is quite low across specifications, suggesting that domestic retail sales and containment measures only explain a small part of variation in port waiting time across countries.

[22] The port terminal Yantian was closed during May to contain the spread of COVID-19. In August, service at the Ningbo-Zhoushan port terminal was reduced terminal in Shenzhen closed for almost a week in late May after port workers tested positive for COVID-19.

[23] Data was kindly updated by Yang Liu.

[24] Sample of countries are: Brazil, Canada, Columbia, Germany, Denmark, Spain, United Kingdom, Greece, Indonesia, Italy, Japan, Korea, Mexico, Netherlands, Poland, Thailand, Turkey, and U.S.

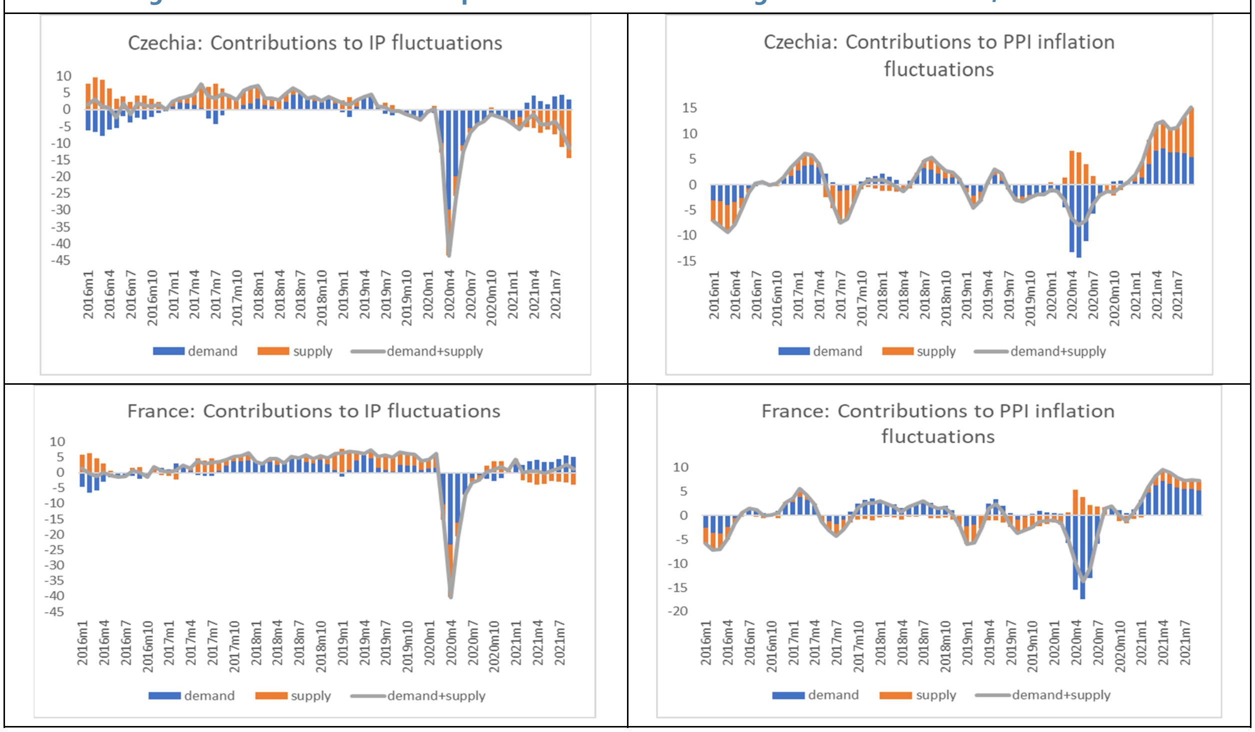
Table 1: Determinants of port waiting time

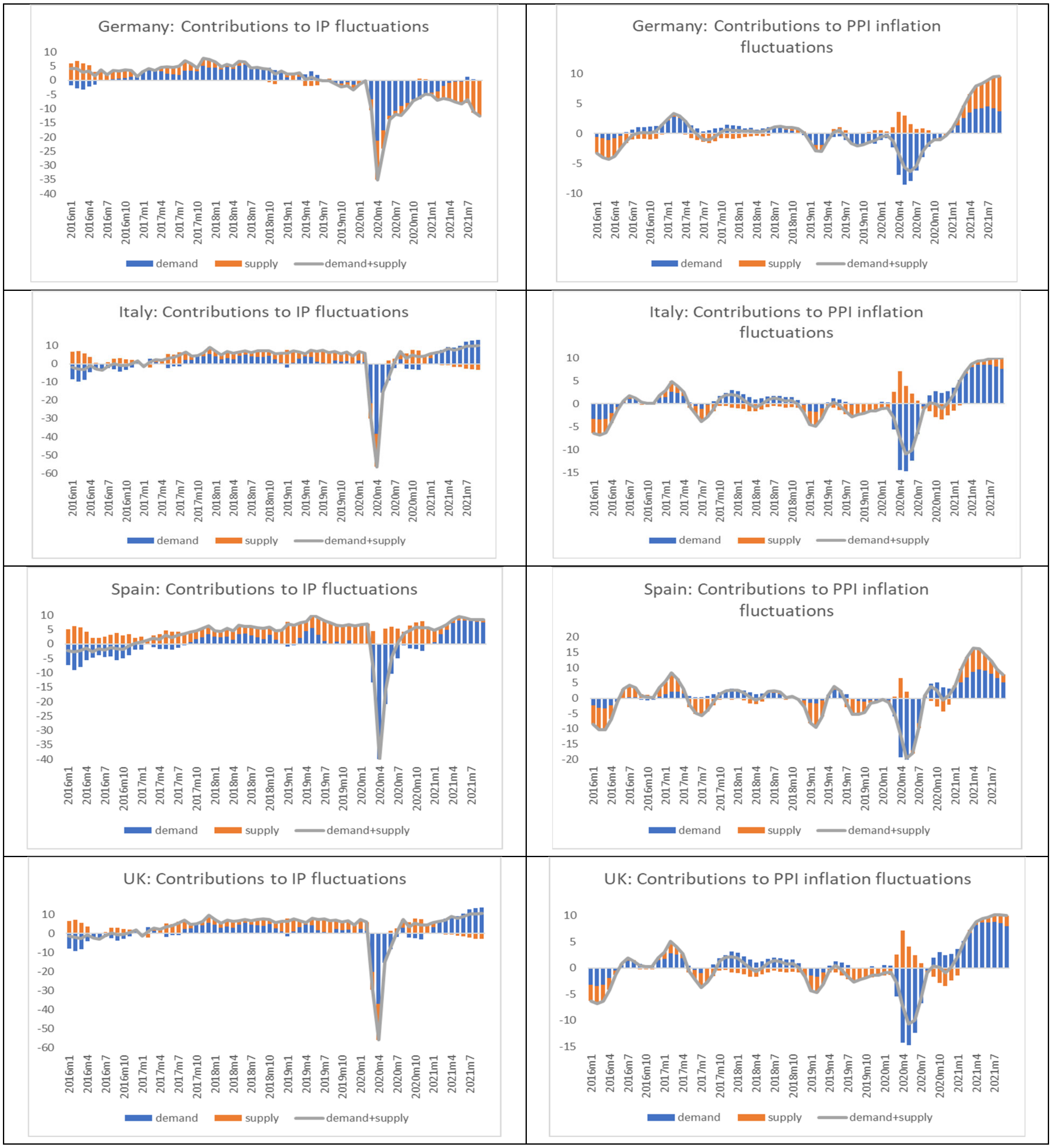
	(1)	(2)	(3)	(4)
VARIABLES	Avg. wait time	Avg. wait time	Avg. wait time	Avg. wait time
L.avg wait time		0.365***		0.333***
		(0.0524)		(0.0518)
Containment measures	0.0448***	0.0314**	0.0313	0.0224
	(0.0148)	(0.0129)	(0.0551)	(0.0531)
Retail sales (yoy)	0.122***	0.0792*	0.310***	0.234***
	(0.0463)	(0.0461)	(0.0537)	(0.0555)
Observations	1,534	1,515	1,534	1,515
R-squared	0.016	0.147	0.019	0.129
Time FE	No	No	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Region	All	All	All	All
Number of countries	19	19	19	19
Number of months	81	80	81	80

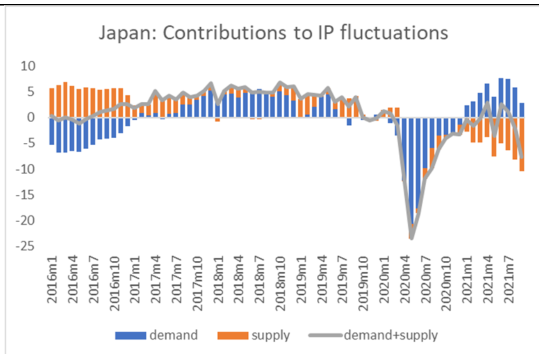
Driscoll-Kraay standard errors are reported in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

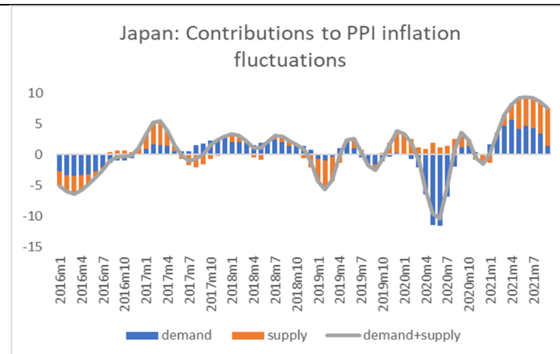
Annex 2. Additional SVAR results

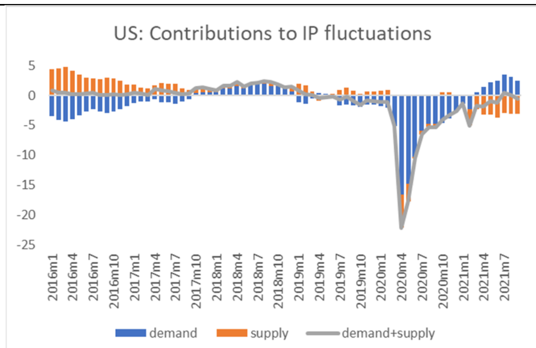
Figure A2.1. Historical decompositions of manufacturing IP and PPI inflation, 2016-2021

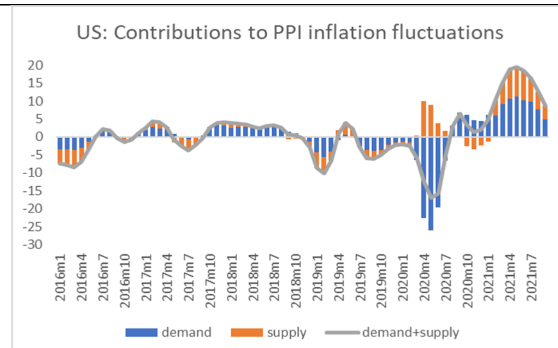


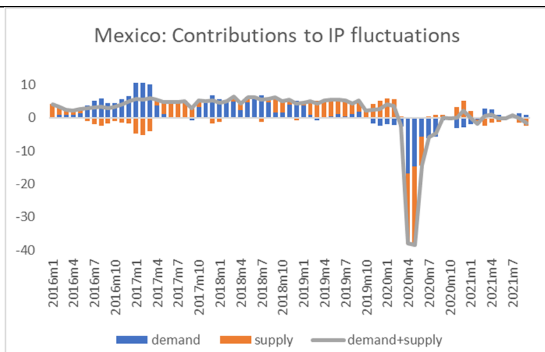

Germany: Contributions to IP fluctuations
demand supply demand+supply
Germany: Contributions to PPI inflation fluctuations
demand supply demand+supply
Italy: Contributions to IP fluctuations
demand supply demand+supply
Italy: Contributions to PPI inflation fluctuations
demand supply demand+supply
Spain: Contributions to IP fluctuations
demand supply demand+supply
Spain: Contributions to PPI inflation fluctuations
demand supply demand+supply
UK: Contributions to IP fluctuations
demand supply demand+supply
UK: Contributions to PPI inflation fluctuations
demand supply demand+supply

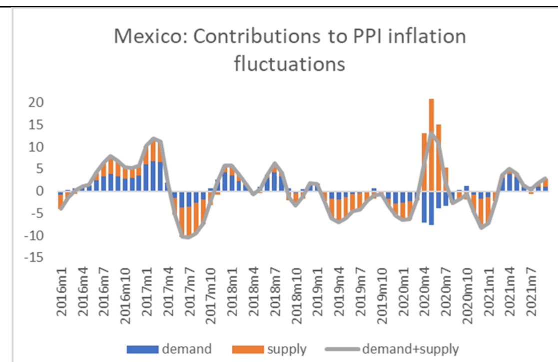

Japan: Contributions to IP fluctuations
demand
supply
demand+supply

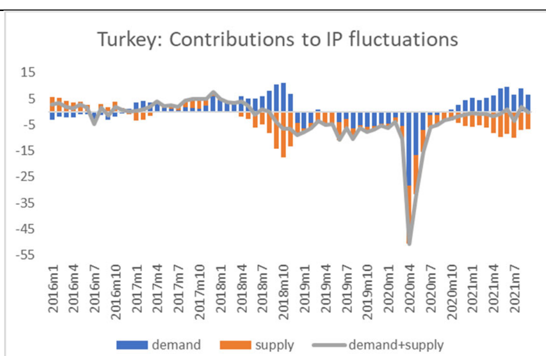

Japan: Contributions to PPI inflation fluctuations
demand
supply
demand+supply


US: Contributions to IP fluctuations
demand
supply
demand+supply


US: Contributions to PPI inflation fluctuations
demand
supply
demand+supply


Mexico: Contributions to IP fluctuations
demand
supply
demand+supply


Mexico: Contributions to PPI inflation fluctuations
demand
supply
demand+supply


Turkey: Contributions to IP fluctuations
demand
supply
demand+supply

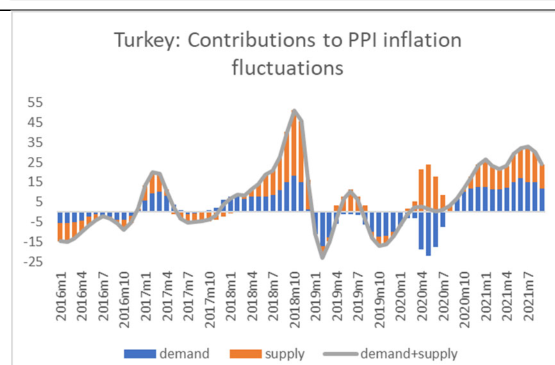
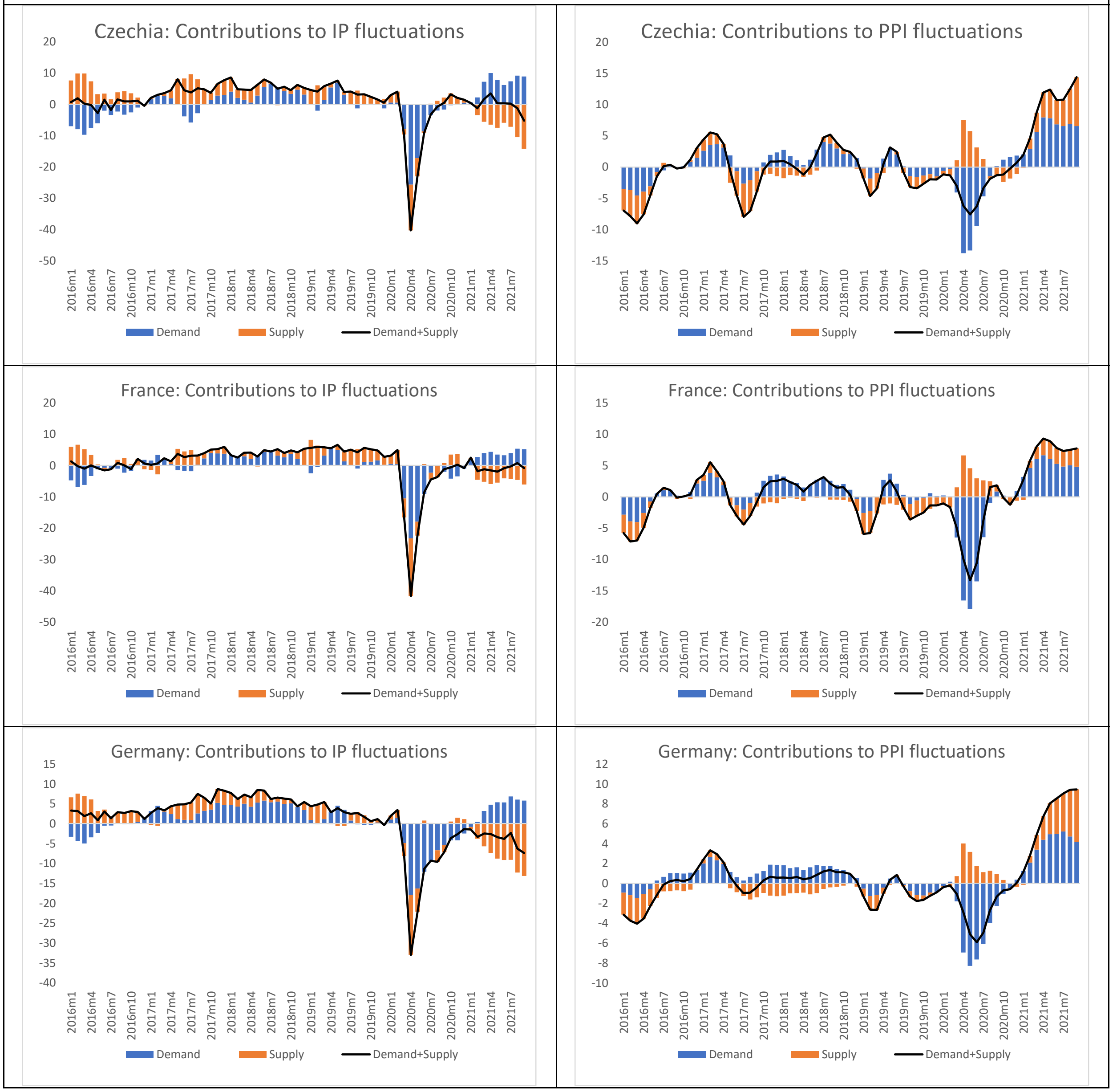
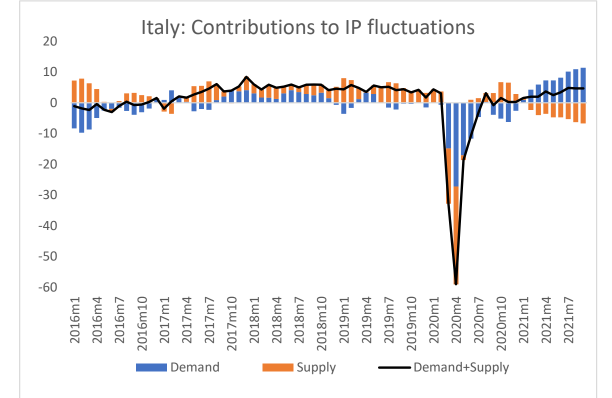
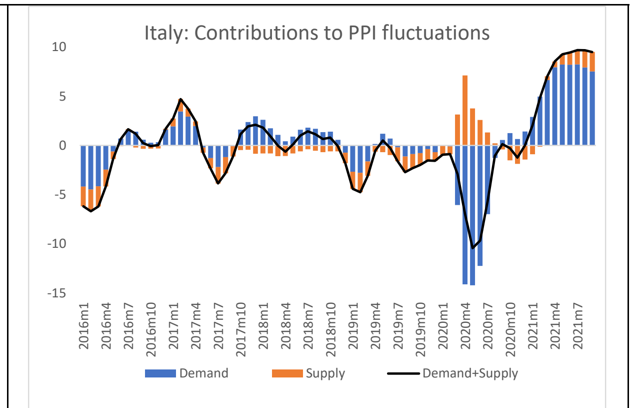
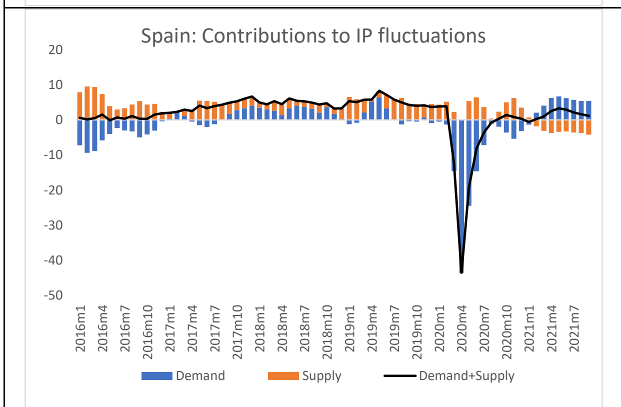

Turkey: Contributions to PPI inflation fluctuations
demand
supply
demand+supply

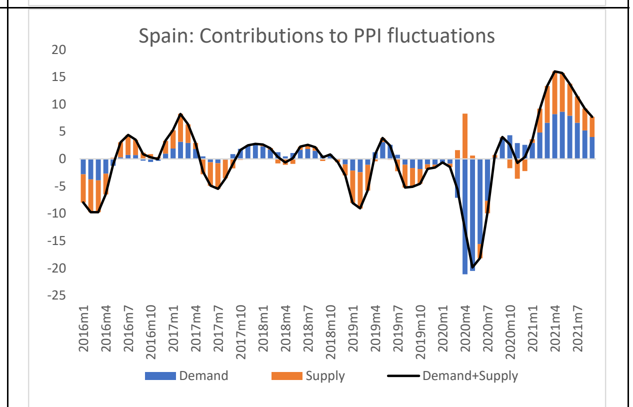
Figure A2.2. Historical Decompositions for the Quadratic Trend Version of the Bivariate SVAR Estimation, 2016-2021

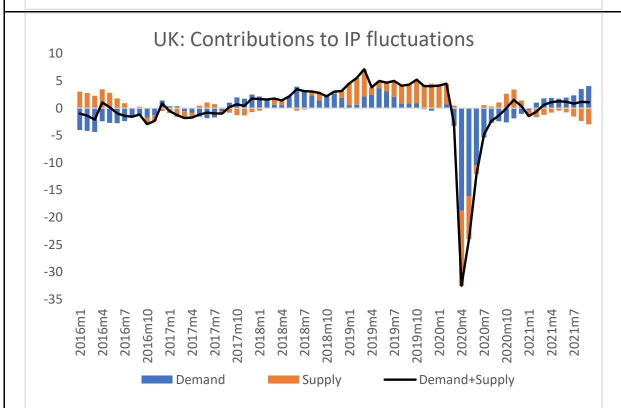


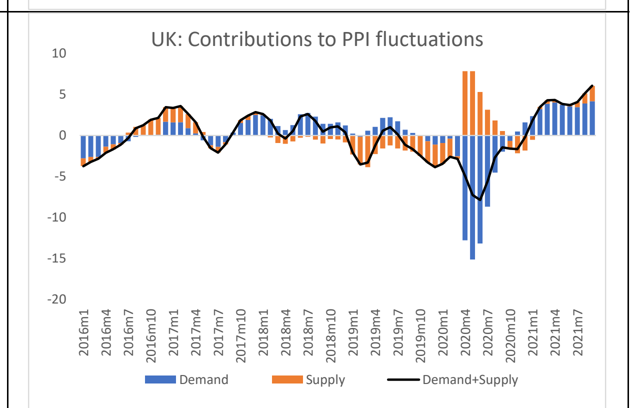

Italy: Contributions to IP fluctuations
20
10
0
-10
-20
-30
-40
-50
-60
2016m1 2016m4 2016m7 2016m10 2017m1 2017m4 2017m7 2017m10 2018m1 2018m4 2018m7 2018m10 2019m1 2019m4 2019m7 2019m10 2020m1 2020m4 2020m7 2020m10 2021m1 2021m4 2021m7
Demand
Supply
Demand+Supply

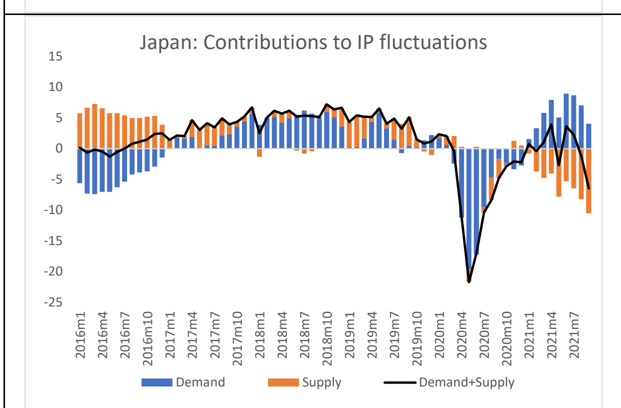

Italy: Contributions to PPI fluctuations
10
5
0
-5
-10
-15
2016m1 2016m4 2016m7 2016m10 2017m1 2017m4 2017m7 2017m10 2018m1 2018m4 2018m7 2018m10 2019m1 2019m4 2019m7 2019m10 2020m1 2020m4 2020m7 2020m10 2021m1 2021m4 2021m7
Demand
Supply
Demand+Supply

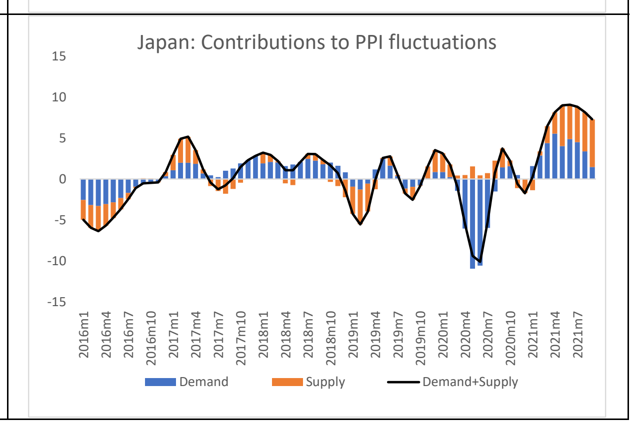

Spain: Contributions to IP fluctuations
20
10
0
-10
-20
-30
-40
-50
2016m1 2016m4 2016m7 2016m10 2017m1 2017m4 2017m7 2017m10 2018m1 2018m4 2018m7 2018m10 2019m1 2019m4 2019m7 2019m10 2020m1 2020m4 2020m7 2020m10 2021m1 2021m4 2021m7
Demand
Supply
Demand+Supply


Spain: Contributions to PPI fluctuations
20
15
10
5
0
-5
-10
-15
-20
-25
2016m1 2016m4 2016m7 2016m10 2017m1 2017m4 2017m7 2017m10 2018m1 2018m4 2018m7 2018m10 2019m1 2019m4 2019m7 2019m10 2020m1 2020m4 2020m7 2020m10 2021m1 2021m4 2021m7
Demand
Supply
Demand+Supply


UK: Contributions to IP fluctuations
10
5
0
-5
-10
-15
-20
-25
-30
-35
2016m1 2016m4 2016m7 2016m10 2017m1 2017m4 2017m7 2017m10 2018m1 2018m4 2018m7 2018m10 2019m1 2019m4 2019m7 2019m10 2020m1 2020m4 2020m7 2020m10 2021m1 2021m4 2021m7
Demand
Supply
Demand+Supply


UK: Contributions to PPI fluctuations
10
5
0
-5
-10
-15
-20
2016m1 2016m4 2016m7 2016m10 2017m1 2017m4 2017m7 2017m10 2018m1 2018m4 2018m7 2018m10 2019m1 2019m4 2019m7 2019m10 2020m1 2020m4 2020m7 2020m10 2021m1 2021m4 2021m7
Demand
Supply
Demand+Supply


Japan: Contributions to IP fluctuations
15
10
5
0
-5
-10
-15
-20
-25
2016m1 2016m4 2016m7 2016m10 2017m1 2017m4 2017m7 2017m10 2018m1 2018m4 2018m7 2018m10 2019m1 2019m4 2019m7 2019m10 2020m1 2020m4 2020m7 2020m10 2021m1 2021m4 2021m7
Demand
Supply
Demand+Supply


Japan: Contributions to PPI fluctuations
15
10
5
0
-5
-10
-15
2016m1 2016m4 2016m7 2016m10 2017m1 2017m4 2017m7 2017m10 2018m1 2018m4 2018m7 2018m10 2019m1 2019m4 2019m7 2019m10 2020m1 2020m4 2020m7 2020m10 2021m1 2021m4 2021m7
Demand
Supply
Demand+Supply

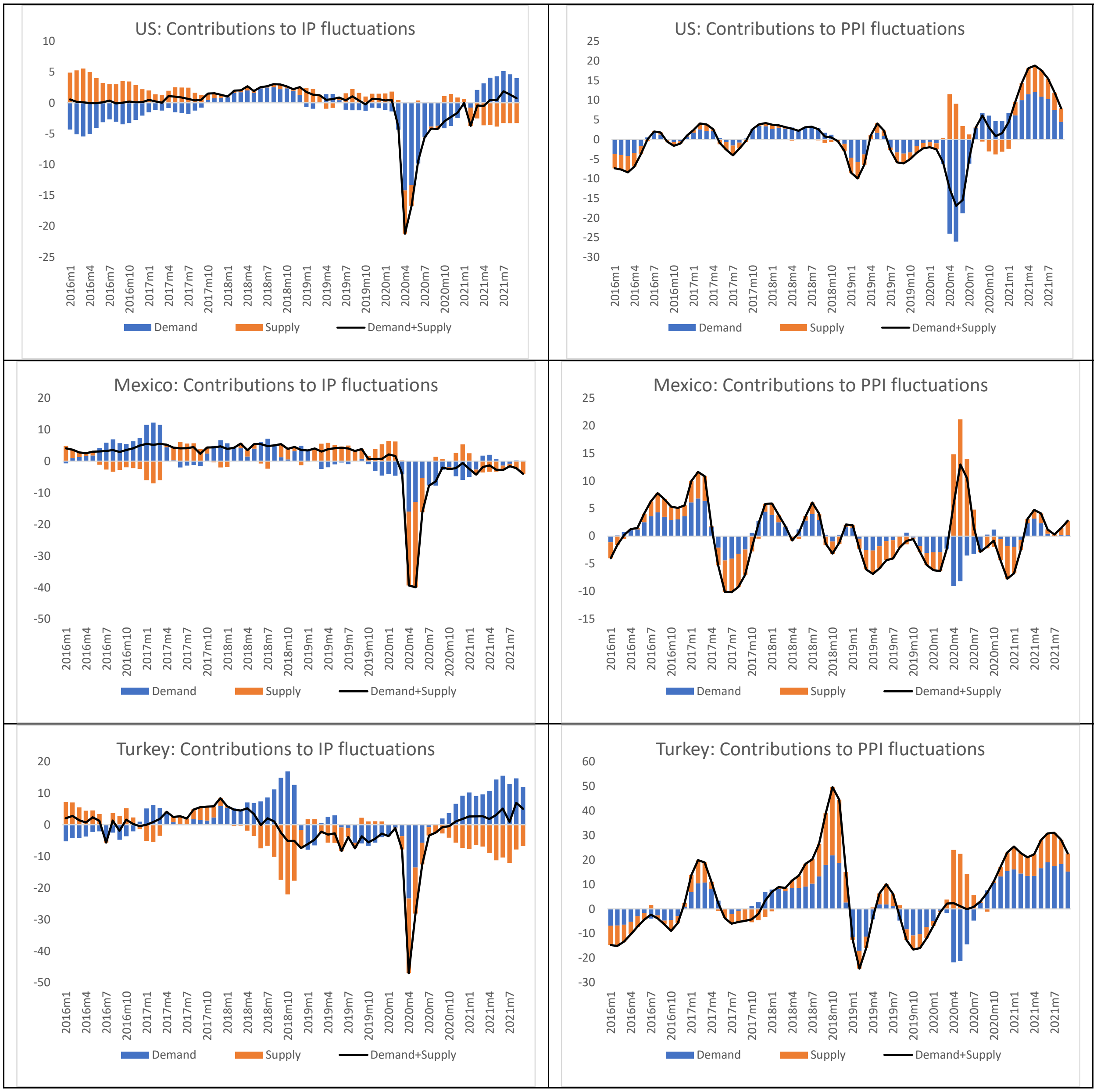
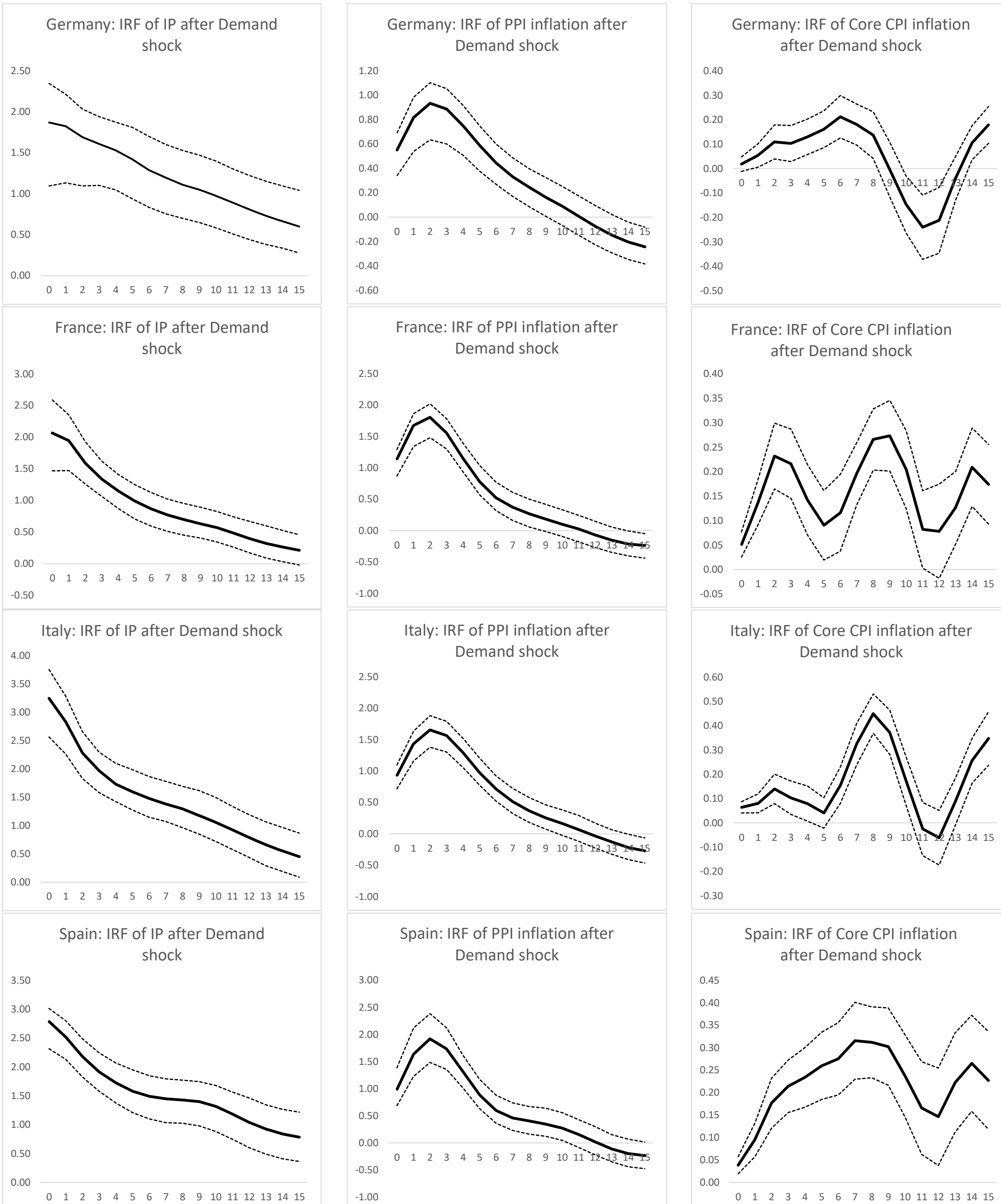
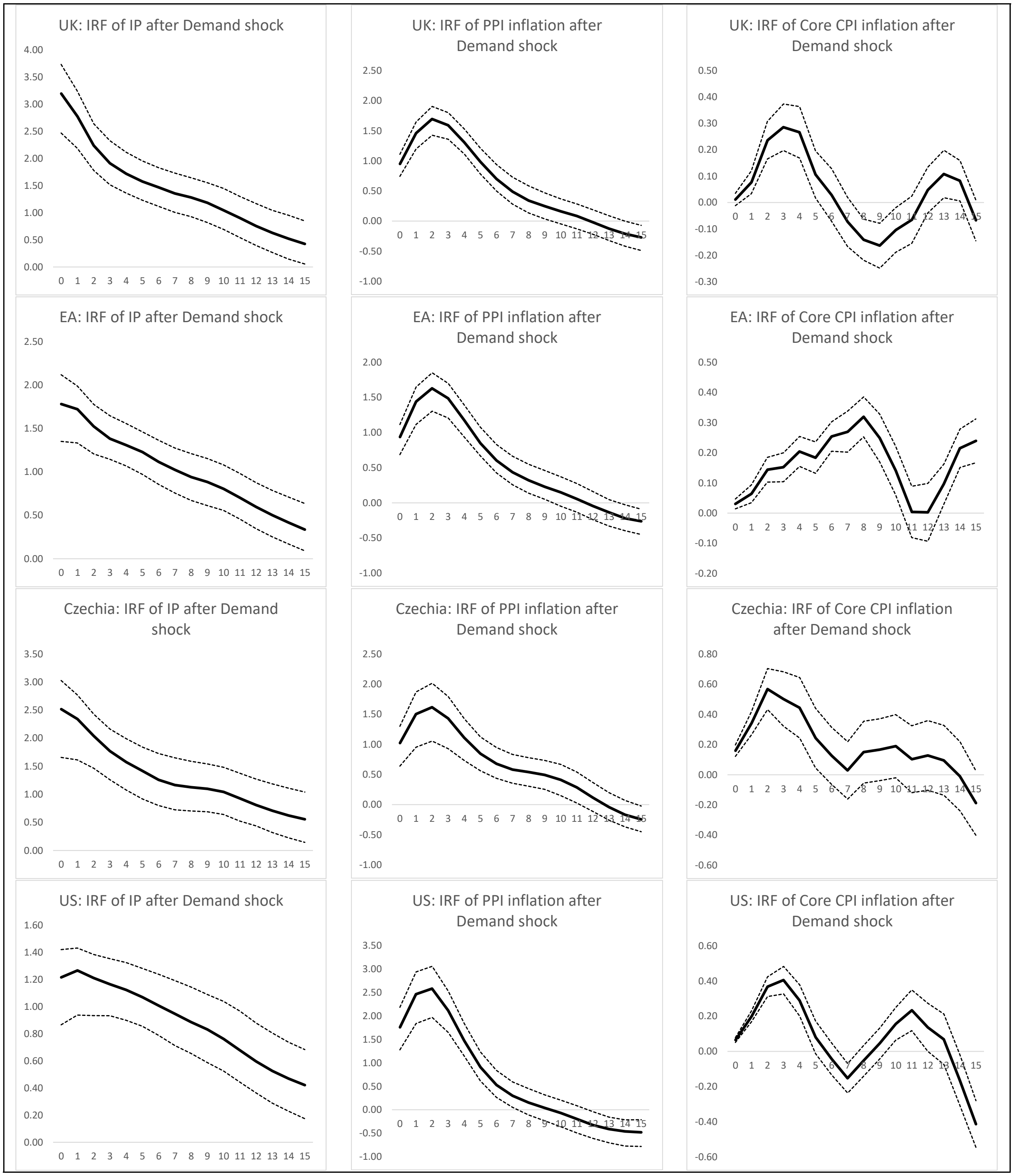

US: Contributions to IP fluctuations
US: Contributions to PPI fluctuations
Mexico: Contributions to IP fluctuations
Mexico: Contributions to PPI fluctuations
Turkey: Contributions to IP fluctuations
Turkey: Contributions to PPI fluctuations
2016m1 2016m4 2016m7 2016m10 2017m1 2017m4 2017m7 2017m10 2018m1 2018m4 2018m7 2018m10 2019m1 2019m4 2019m7 2019m10 2020m1 2020m4 2020m7 2020m10 2021m1 2021m4 2021m7
Demand
Supply
Demand+Supply

Figure A2.3. Impulse Response Functions for Demand Shocks




UK: IRF of IP after Demand shock
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
UK: IRF of PPI inflation after Demand shock
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
UK: IRF of Core CPI inflation after Demand shock
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
EA: IRF of IP after Demand shock
2.50
2.00
1.50
1.00
0.50
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
EA: IRF of PPI inflation after Demand shock
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
EA: IRF of Core CPI inflation after Demand shock
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Czechia: IRF of IP after Demand shock
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Czechia: IRF of PPI inflation after Demand shock
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Czechia: IRF of Core CPI inflation after Demand shock
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
US: IRF of IP after Demand shock
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
US: IRF of PPI inflation after Demand shock
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
US: IRF of Core CPI inflation after Demand shock
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

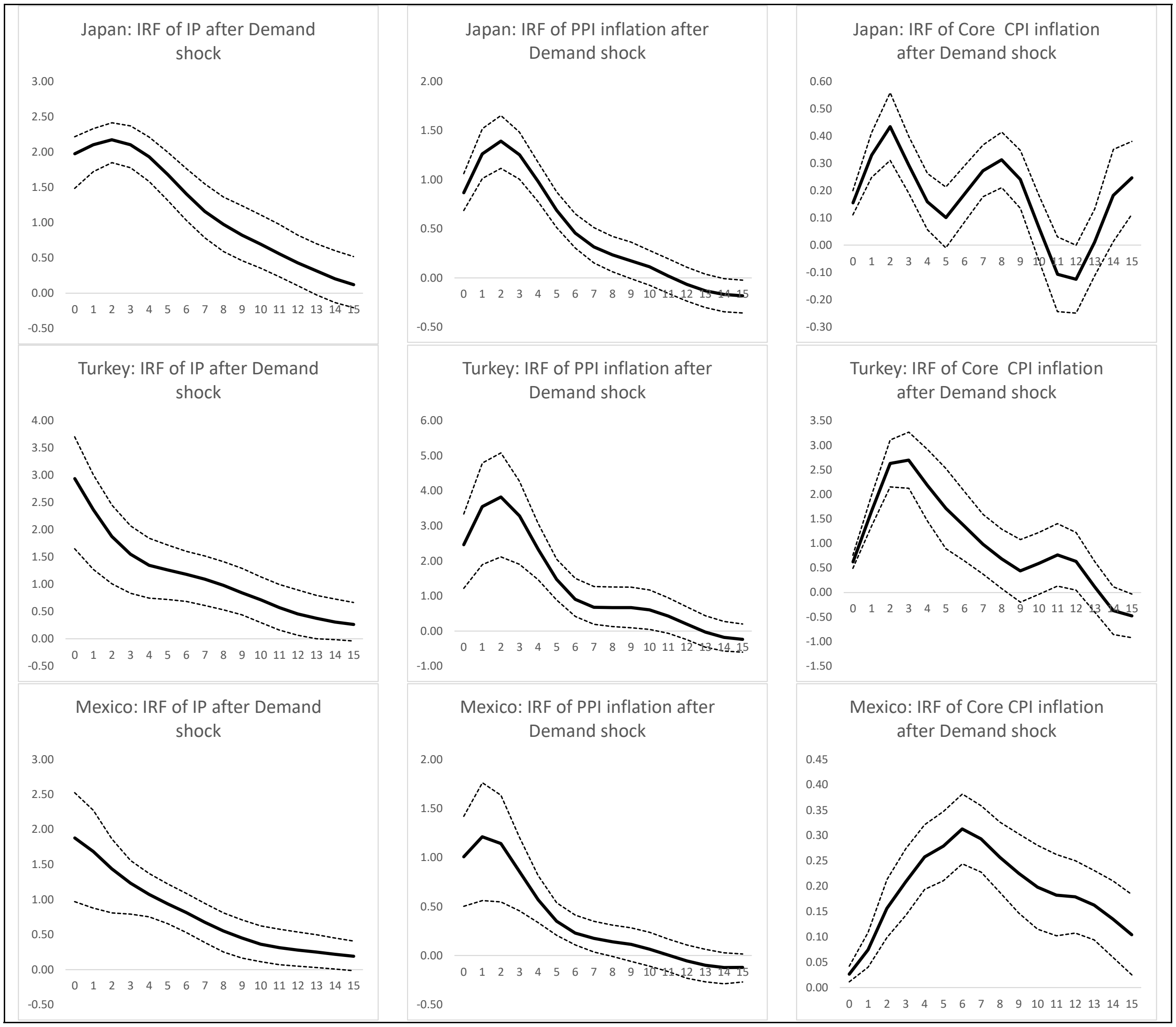
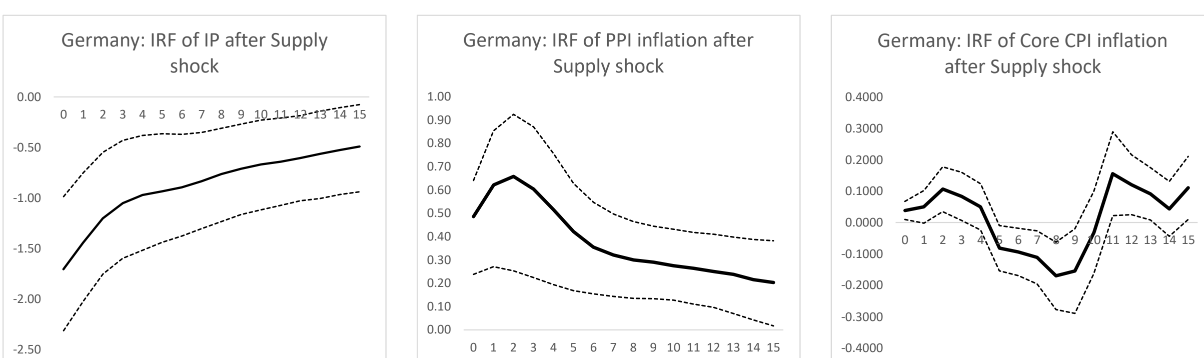
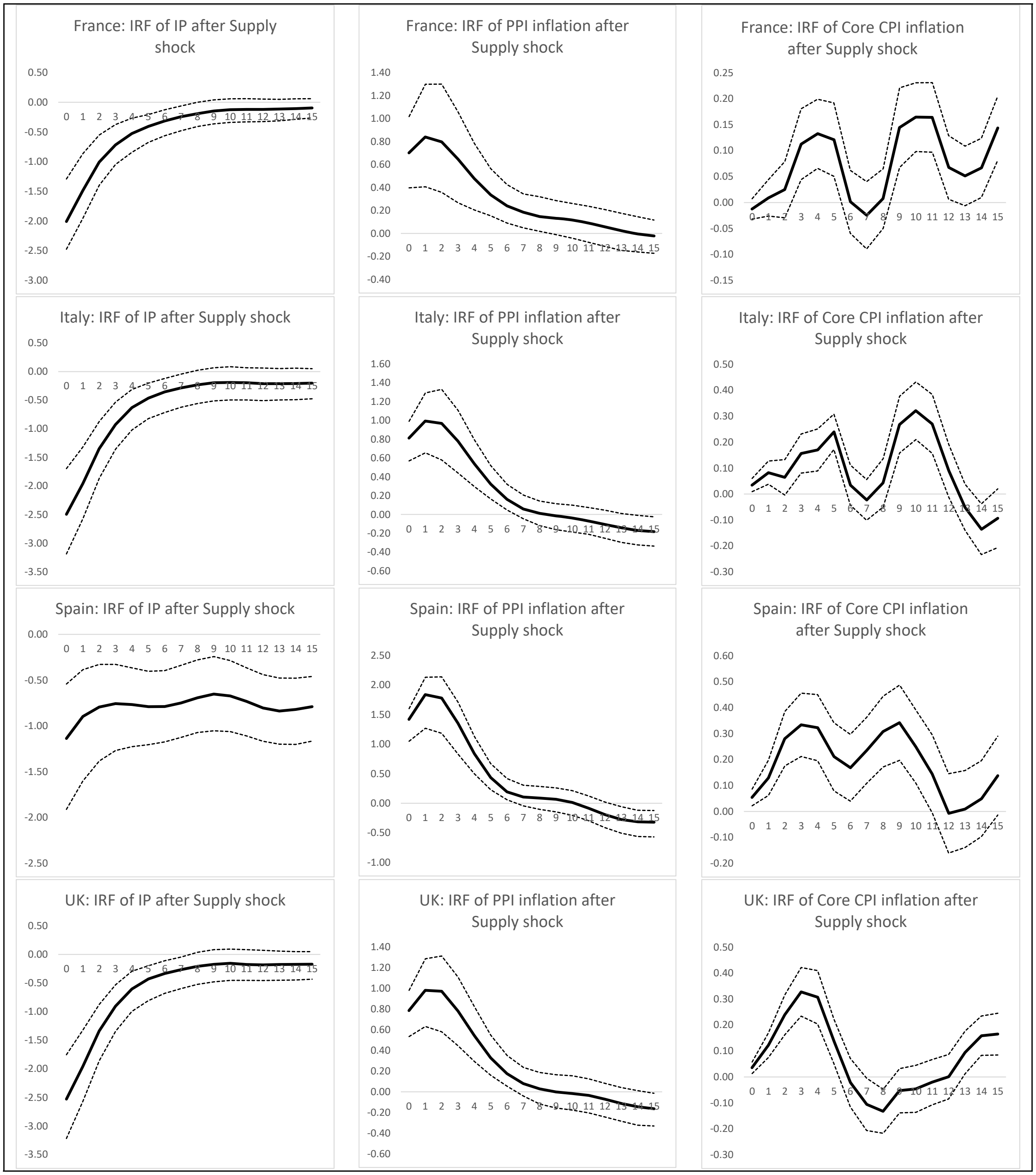
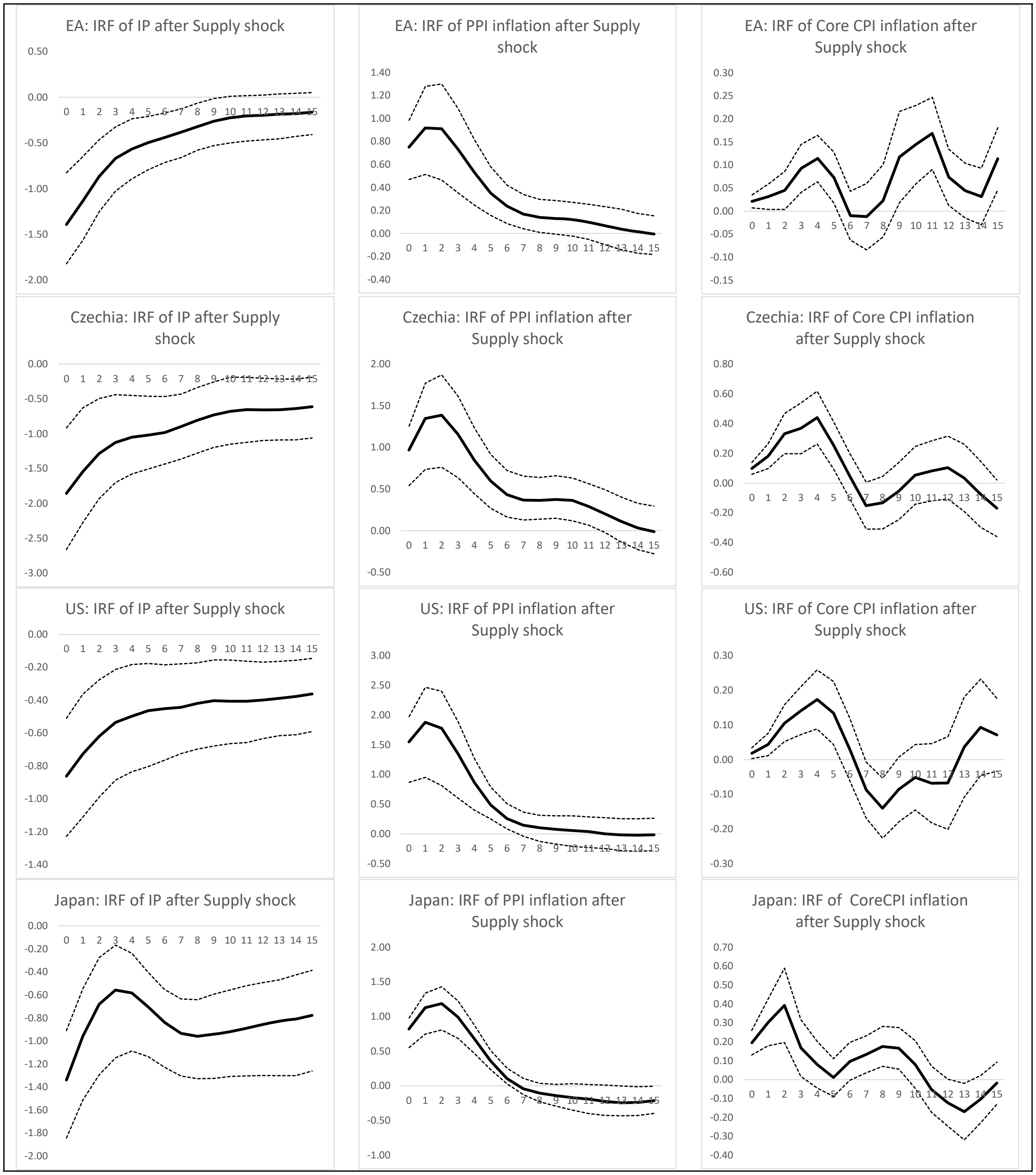
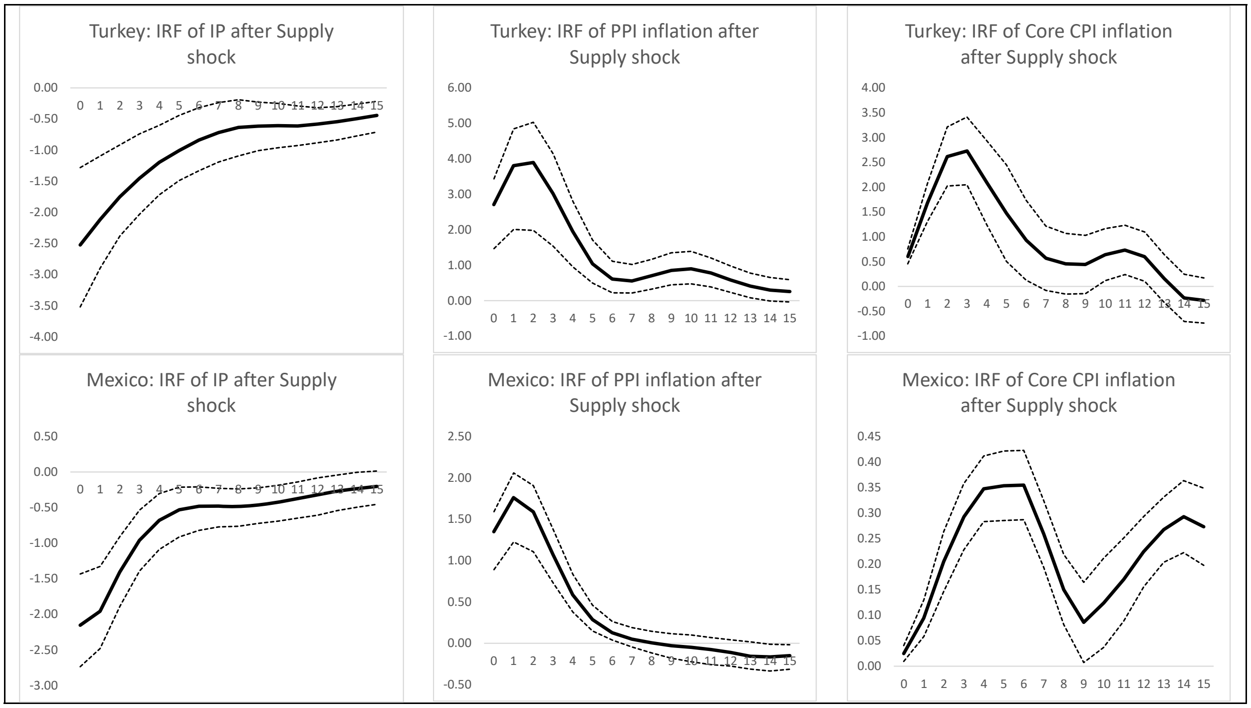


Figure A2.4. Impulse Response Functions for Supply Shocks




France: IRF of IP after Supply shock
France: IRF of PPI inflation after Supply shock
France: IRF of Core CPI inflation after Supply shock
Italy: IRF of IP after Supply shock
Italy: IRF of PPI inflation after Supply shock
Italy: IRF of Core CPI inflation after Supply shock
Spain: IRF of IP after Supply shock
Spain: IRF of PPI inflation after Supply shock
Spain: IRF of Core CPI inflation after Supply shock
UK: IRF of IP after Supply shock
UK: IRF of PPI inflation after Supply shock
UK: IRF of Core CPI inflation after Supply shock


EA: IRF of IP after Supply shock
0.50
0.00
-0.50
-1.00
-1.50
-2.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
EA: IRF of PPI inflation after Supply shock
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
EA: IRF of Core CPI inflation after Supply shock
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Czechia: IRF of IP after Supply shock
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Czechia: IRF of PPI inflation after Supply shock
2.00
1.50
1.00
0.50
0.00
-0.50
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Czechia: IRF of Core CPI inflation after Supply shock
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
US: IRF of IP after Supply shock
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
-1.40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
US: IRF of PPI inflation after Supply shock
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
US: IRF of Core CPI inflation after Supply shock
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Japan: IRF of IP after Supply shock
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
-1.40
-1.60
-1.80
-2.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Japan: IRF of PPI inflation after Supply shock
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Japan: IRF of CoreCPI inflation after Supply shock
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15



Annex 3. Methodology Used to Assess the Drivers of Supply Bottlenecks

Data Description

The key dependent variables used in the analysis are manufacturing (subsector) industrial production— converted to percent deviations from their 2019 levels, and supply shocks identified by SVAR. The independent variables include government containment stringency index (Oxford COVID-19 Government Response Tracker, Blavatnik School of Government, University of Oxford), labor shortages—proxied by share of firms reporting production capacity constrained by insufficient labor (Confederation of British Industry, European Commission, and U.S. Census). Global value chain information is from the Inter-Country Input-Output tables (OECD, 2015).

Empirical Strategy

To test whether the impact of shutdowns on a sector depends on its differentiated inputs usage, we follow Acemoglu and others (2016), treating shutdowns as exogeneous shocks and allowing the marginal impact of shutdowns to vary by sector's differentiated inputs usage. To calculate $Share_{is}^{diff}$, the degree of country i sector s' differentiated input usage, we divide all sectors into two groups: those that produce homogeneous goods and those producing differentiated goods, based on the classification by Rauch (1999). We then calculate the share of inputs into sector *s* in country *i* from differentiated-goods-producing sectors, using input-output tables.

To calculate $Shutdown_{ist}$, we first interact measures of sectors' teleworkability (Dingel and Neiman, 2020) with measures of shutdown stringency in the domestic economy to create country-specific sectoral shutdown series. Then $Shutdown_{ist}$ for sector *s* of country *i* in month *t* is given by the average of the shutdown series of the domestic and foreign input-providing sectors, weighted (w_{is}^{jr}) by the share of country *j* and sector *r*'s into the output of sector *s* in country *i*.

$$Shutdown_{ist} = \sum_{j}\sum_{r} Shutdown_{jt} \cdot teleworkability_{r} \cdot w_{is}^{jr}$$

The regressions employ a monthly country-sector panela monthly panel of 21 European countries and 15 manufacturing subsectors.[25] The empirical specification includes shutdowns and the interaction term of shutdowns and differentiated inputs usage, controlling for lagged production and quarterly dummies.

$$IP_{ist} = \alpha IP_{ist-1} + \beta_1 Shutdown_{ist} + \beta_2 Share_{is}^{diff} \cdot Shutdown_{ist} + \Gamma \cdot \mathbb{1}_{quarter} + \epsilon_{ist}$$

The estimates confirm that sectors that rely more on differentiated inputs—which are hard to replace in response to disruptions—are more prone to shutdowns. A one standard deviation increase in the share of differentiated inputs usage would double the marginal impact of shutdowns, lowering the coefficient of shutdowns' marginal impact from -0.11 to -0.23 (Table A2, column 1). The coefficients remain significant when furthering controlling for country-sector fixed effects (Table A2, column 2).

To assess how much shutdowns and domestic labor supply weakness could explain the supply shocks estimated from the SVAR, we turn to a country-level analysis.[26] The country-level $Shutdown_{it}$ is constructed similarly to that at the country-sector-level, averaging the home and foreign countries' shutdowns weighted (w_{i}^{j}) by the share of country *j*'s output used in the total output of country *i*.

$$Shutdown_{it} = \sum_{j} Shutdown_{jt} \cdot w_{i}^{j}$$

Given the previously-shown cross-country diversity, we allow the marginal impact of shutdowns to vary based on countries exposure to shutdowns, proxied by above-examined three characteristics—the share of auto sector, the dependence on foreign value added, and the downstreamness in global value chain.

[25] Based on the availability of manufacturing subsector industrial production data, the sample includes 21 European countries, Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Lithuania, Latvia, Netherlands, Poland, Portugal, Romania, Spain, Sweden, United Kingdom; and 15 manufacturing subsectors, denoted by NACE Rev2 code, 10T12, 13T15, 16T18, 19, 20T21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31T33.

[26] The sample includes Czech Republic, France, Germany, Italy, Japan, Mexico, Spain, Turkey, United Kingdom, United States, whose supply shocks have been estimated by SVAR. Japan and Mexico are not included with regressions that contain labor shortages, due to the lack of firm survey data.

Labor shortages are proxied by the share of firms reporting their production capacity constrained by insufficient workers base on firm surveys. Since the supply shock identified by the SVAR represents the shock stemmed from the current month, we control for lagged shutdowns to purge the impact from past shutdowns. The regression specification is as follows:

$$Shock_{it}^{supply} = \beta_1 Share_{it}^{labor\ shortage} + \beta_2 Shutdown_{it} + \beta_3 Exposure_i \cdot Shutdown_{it} + \alpha_i + lag\ Shutdown_{it} + \epsilon_{it}$$

On average, the supply shock would worsen by 2¾ and ⅓, as result of a one standard deviation increase in shutdowns and labor shortages, respectively (Table A2, column 6), and the impacts are similar when including the interaction term of shutdowns and exposures. To see how much shutdowns and labor shortages could account for the variations in the supply shocks, we calculate the "partial" R-square—of shutdowns, for instance—by residualizing supply shocks and shutdowns from labor shortages, and regressing the residualized supply shocks on residualized shutdowns to obtain R-square. Overall,

shutdowns and labor shortages explain 25 and 3 percent of the variation in supply shocks, respectively (Figure 14a).

$$Shock_{it}^{supply} = \beta_1 Share_{it}^{labor\ shortage} \alpha_i + \epsilon_{it} \Rightarrow \widehat{Shock_{it}^{supply}}$$
$$Shutdown_{it} = \beta_1 Share_{it}^{labor\ shortage} \alpha_i + u_{it} \Rightarrow \widehat{Shutdown_{it}}$$
$$\widehat{Shock_{it}^{supply}} = \widehat{Shutdown}_{it} + \lambda + \nu_{it} \Rightarrow \text{partial R-square}$$

Based on these results, we decompose the worsening in supply shocks in 2020/21 relative to 2019 to that from labor shortage increase and shutdowns tightening. On average, they account for about 40 to 50 percent of the supply shocks, with shutdowns contributing 33 to 40 percent and labor shortages contributing another 6 to 10 percent. The estimates from the regression including foreign value share (Table A2, column 8) come out the largest (Figure 14b), but the decomposition results do not differ significantly across different regressions.

Table A3.1 Drivers of Supply Shocks

	Differentiated inputs		Diversity of supply shocks			Drivers of supply shocks			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Lag IP	0.651***	0.359***							
	(0.00)	(0.00)							
Shutdowns	-0.107**	-0.458***	-0.091***		-0.088***	-0.087***	-0.081***		-0.083**
	(0.02)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)		(0.00)
Differentiated goods usage	36.729***	-5.539							
	(0.00)	(0.35)							
Differentiated goods	-1.169***	-0.463**							
×Shutdowns									
Auto share			-0.021*				-0.001*		
×Shutdowns			(0.07)				(0.10)		
Foreign VA share				-0.023**				-0.001**	
×Shutdowns				(0.01)				(0.01)	
Downstreamness					-0.006**				-0.005
Shutdowns					(0.03)				(0.25)
Labor shortages						-0.031**	-0.041**	-0.059**	-0.058**
						(0.04)	(0.02)	(0.02)	(0.02)
Shutdowns:				-0.046*				-0.012	
home				(0.07)				(0.47)	
Shutdowns:				-0.061*				-0.089**	
foreign suppliers				(0.07)				(0.00)	
N	5503	5503	330	330	210	261	261	261	165
R-square	0.549	0.625	0.300	0.312	0.318	0.292	0.295	0.361	0.317

Note: This table shows the country-level regressions estimating the impact of home and foreign shutdowns on industrial production. Standard errors are clustered at country level, and p-values are presented in parentheses. *, **, and *** denote the ten, five and one percent significance level, respectively.

Annex 4. An Overview of the Semiconductor Industry

The production of semiconductors is a large, capital- and innovation-intensive industry, with a complex and global value chain. In 2019, the global market for semiconductors was estimated at about US$420 billion, with US$90 billion in R&D investment and US$110 billion in capital expenditure.[27] The industry relies heavily on pre-competitive basic research that takes place, often collaboratively, in academia, government institutions and the private sector. The production of semiconductors itself has three distinct stages:

i. Design of chips, in which engineers develop the specifications of the electronic components that form an integrated circuit. This stage is knowledge-intensive, employs highly-skilled personnel and uses specialized design software and in many cases reusable architectural building blocks ("IP cores").

[27] Semiconductor Industry Association (2021)

ii. Manufacturing in "foundries" or "fabs", where the integrated circuits from the chip design are "printed" into silicon wafers. This stage is highly capital-intensive: setting up a state-of-the-art foundry can have a cost in the order of US$5-20 billion[28] since it requires specialized machinery, and the manufacturing of semiconductors must take place in so-called "cleanrooms" where particles that could alter the functioning of the chips are filtered out of the air.
iii. Assembly, testing and packaging, in which the silicon wafers produced by the foundries are converted into finished chips ready to be assembled into electronic devices. This stage is relatively labor-intensive.[29]

In turn, these stages of production are supported by an ecosystem of materials, machinery, software, and IP suppliers. Stages (i) and (ii) can either be undertaken within the same firm –the so-called Integrated Device Manufacturer (IDM) model—or by different companies; in the latter case, a "fabless" designer would contract with a foundry to manufacture their chips. In general, all or part of stage (iii) is undertaken by specialized companies called outsourced semiconductor assembly and testing (OSAT) firms. The main downstream users of semiconductors are consumer electronics companies, which use them to produce devices like mobile phones, PCs, and TVs. Outside of the ICT sector, the main downstream users of semiconductors are automakers, but they are estimated to account for only about 10 percent of total chip sales.[30]

Both foundries and OSATs operate in highly concentrated industries, mostly located in Asia. Given the large capital expenditure involved in setting up a foundry, firms need to operate at a large scale to be profitable. This has led to a high market concentration, with a few firms mostly located in Taiwan Province of China, Japan, and South Korea dominating the global industry. According to OECD (2019), in 2018, TSMC (Taiwan Province of China) accounted for 54 percent of the global foundry market share, while the top 10 firms accounted for 87 percent of the global market. Furthermore, East Asia has 75 percent of global production capacity and 100 percent of the capacity for the most advanced chips. The region's competitive advantage in manufacturing is driven by government incentives, a robust infrastructure (particularly reliable power and water supply, and well-functioning transportation and logistics networks), and a skilled workforce at competitive rates.[31] Despite being relatively more labor intensive, OSATs are also highly concentrated in East Asia, particularly in Taiwan Province of China and China, and with an increasing role for Southeast Asia (particularly Malaysia, Vietnam and the Philippines) where labor costs

[28] Semiconductor Industry Association (2021).

[29] That is, this stage does not require as much R&D or costly equipment as stages (i) and (ii), but it is still R&D- and capital-intensive relative to other industries.

[30] See OECD (2019), Table 1.4.

[31] By one estimate, as much as 40–70 percent of the cost differential between locating a foundry in the U.S. or in Asia is explained by government incentives. See Semiconductor Industry Association (2021).

are generally lower. OECD (2019) estimates that in 2018 the largest firm[32] and the top 10 OSAT firms had a market share of 40 percent and 91 percent, respectively. While the U.S. and Europe have a relatively small participation in semiconductor manufacturing, they have a large presence in the more knowledge-intensive sectors of the industry, particularly fabless design, and development of specialized software, IP cores and equipment used at foundries.[33]

High regional specialization of the supply chain has created vulnerabilities. Regional specialization has allowed significant efficiency gains, but with various stages of production concentrated in a few firms and a handful of countries, the industry is vulnerable to geopolitical tensions and to natural disasters, epidemics, or infrastructure failures. The risk of geopolitical tensions came to the fore in the years before the pandemic, with Japan announcing potential export controls to South Korea in 2019 that could have affected exports of chemicals essential to semiconductor manufacturing; and the U.S. imposing export controls to China of semiconductors and other critical equipment containing U.S.-developed technology.[34] These vulnerabilities have fueled a desire for increased self-sufficiency, particularly in the U.S. and Europe which have a very limited participation in the manufacturing process. While full renationalization of global value chains would be prohibitively expensive, increased grants and tax incentives could potentially lead production to become less concentrated geographically.

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[33] See McKinsey (2020), Exhibit 2.

[34] See Bown (2020).

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