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The viral effects of foreign trade and supply networks in the euro area

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Abstract

Containment measures of COVID-19 have generated a chain of supply and demand shocks around the globe with heterogeneous fallout across industries and countries. We quantify their transmission via foreign trade with a focus on the euro area where deep firms integration within regional supply chains and strong demand linkages act as a magnification mechanism. We estimate that spillover effects in the euro area from suppression measures in one of the five main euro area countries range between 15-28% the size of the original shock; negative foreign demand shocks depress euro area aggregate activity by about a fifth the size of the external shock and a fourth of the total effect is due to indirect propagation through euro area supply chain. Last, reopening to regional tourism softened the contraction of aggregate activity due to travel and tourism bans by about a third in the euro area. Our findings suggest that enhanced coordination of recovery plans would magnify their beneficial effects.

Keywords: COVID-19, supply networks, GVCs, euro area foreign trade
JEL-Classification: F14, F23, F40

1 Introduction

In the attempt to reduce the spreading of the COVID-19, governments have introduced containment measures triggering a chain of supply and demand shocks adversely affecting their economies besides the effects produced directly by the disease itself. Commercial and business activities were closed, people's movement constrained to the mere necessity, and travelling possibilities were limited to essential business and force majeure cases. The severe repercussions on the spending capability, consumption and investment preferences of economic agents in each country have propagated across the world, with intensity depending on the degree of interconnectedness of economies and industries.

A lively literature on the macroeconomic effects of COVID-19 has been rapidly expanding; the CEPR has dedicated a special collection to the COVID economics with vetted and real time papers responding to the urge of understanding the economic mechanisms (see CEPR (2020)), measuring temporary and permanent effects, studying aspects of our lives most concerned by this pandemic and above all rapidly bringing results to the attention of a large audience.[1] Many contribution touched also upon the effects of containment and lockdown measures on GDP and trade of partner economies or focusing on the effects of social distancing.[2]

In a similar vein, this work responded to the urge of informing the debate among institutions at the outbreak of the pandemic in Europe. The analysis employs international input-output tables, i.e. classical Leontief input-output tables that are extended by a country dimension, to evaluate the transmission via foreign trade of adverse shocks generated by lockdown and containment measures across the euro area. Specifically, we take the Asian Development Bank's *Multiregional Input-Output Table* (MRIO) as a base. From this, we extract descriptive statistics, such as aggregate production, demand, trade and value-added content of trade. We then apply shocks to the MRIO, which can affect (intermediate) demand or output of individual sectors or entire countries and which are calibrated according to the specific scenario. Afterwards, we extract the same descriptive statistics again and compare them to evaluate the effect of the shock. [3]

There are several advantages from this choice. Compared with alternative standard analysis, resorting to a full representation of country-sector production and demand linkages we can evaluate spillovers and spills back effects from any idiosyncratic shock on output, value added, trade of domestic and foreign production of any other country and sector

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[1]See https://cepr.org/content/covid-economics-vetted-and-real-time-papers-0 for a

[2]See Di Nino and Veltri (2020), Barrot, Grassi and Sauvagnat (2020), Navaretti, Calzolari, Dossena, Lanza and Pozzolo (2020)), Bonadio, Huo, Levchenko and Pandalai-Nayar (2020), Bodenstein, Corsetti and Guerrieri (2020), Farhi and Baqaee (2020),Altomonte C. (2020), OECD (2020c),OECD (2020e),Maliszewska, Mattoo and Van Der Mensbrugghe (2020), Javorcik (2020), see also Brodeur, Gray, Islam and Bhuiyan (2020) for a literature review).

[3]For a more detailed description of the MRIO, descriptive statics extraction, as well as a description of shock design, shock calibration and shock application, see Annex A.1-A.2.

within a single overarching framework. [4]

The methodology we adopt allows a decomposition of the full shock transmission mechanism into direct effects on trading partners and indirect spillovers on third countries via trading partners; likewise on industries that are indirectly affected by lower inputs demand and supply from sectors targeted by suppression measures (see annex A.3 for further details on transmission channels). Moreover it accommodates the treatment of shocks different in nature, and in particular single country shocks (unilateral), multi country shocks (plurilateral), sector specific and foreign trade specific shocks. Finally given the strong interdependence of euro area economies and considered that the focus of this note is on euro area originated shocks and repercussions on the euro area of foreign originated shocks, the above said properties become all the more relevant.

We evaluate the transmission of several type of shocks in the Euro Area economy; domestic supply shocks, foreign demand shocks and shocks that affect some industries specifically, like tourism, travel hospitality and food services. Spillover effects in the euro area are very substantial and caused by the strong final demand linkages and the architecture of a dense regional supply chains. In this context, analyses based on methodologies that disengage from considering euro area interconnectedness are likely to underestimate the effective impact of COVID-19 containment measures.[5]

The analyses rest on some key assumptions and face certain limitations. It strips out price effects of implemented policies; because the set-up is static it ignores eventual permanent changes in the structure of economies ensuing from diversification of essential production processes and changes in lifestyle, time allocation across activities, consumption preferences and daily needs. Besides, the calibration of shocks triggered by containment measures is based on GDP predictions for 2020, hence the analysis focuses on the short-medium run consequences and recovery plans and public policies influence the outcome only if embedded in the forecasts of aggregate output for 2020 (see annex A.1 for further details on data and methodology).

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[4]Conversely, if shock transmission across countries are evaluated by net trade exposure, indirect spillover from foreign demand to demand of upstream inputs as well as supply of non-traded downstream sectors are neglected and the exercise underestimate the transmission power of the foreign trade channel. In particular a global but fully symmetric shock, which affects each economy to the same extent, would not bear consequences on GDP growth according to a standard analysis of net trade exposure because imports and exports are expected to move in tandem and be equally affected. However it is difficult to argue that the global shock only hits each economy via domestic channels in this case.

[5]Several contributions in the literature on GVCs show that production networks propagate idiosyncratic shocks and can be a source of aggregate fluctuations. Acemoglu, Carvalho, Ozdaglar and Tahbaz-Salehi (2012), Acemoglu, Akcigit and Kerr (2016) Gabaix (2011).

2   Euro area-wide repercussions of containment measures in the five largest economies

COVID-19 migrated on euro area territories before spreading to the rest of western hemisphere, containment measures outside of China were thereby first enforced in Europe. We assess spillovers from the lockdowns, temporary closure, mobility restraints and other containment measures adopted by the five largest euro area economies (Germany, France, Italy, Spain and the Netherlands) since early March 2020.

The sectoral distribution of production shocks reflects the expected differential impact of containment measures across industries.[6] Trade, transport accommodation and food services are among the hardest hit in all countries, while in manufacturing there are significant differences across sectors and some specific productions (some drugs and food for instance) as well as ICT services have benefited in the short run(see Annex A.2 for sectoral calibration of initial shocks). We take as initial aggregate GDP shocks to the five largest euro area economies in 2020 the predictions on euro area economies of the broad macroeconomic projection exercise (BMPE) of June 2020.[7] However the overall shock magnitude does not matter for the computation of shock transmission in this framework, since results can be scaled up proportionally (see Annex A.1 for details).

According to our evaluations the transmission of domestic shocks in the five largest economies induced by COVID-19 suppression measures, to the aggregate activity of the rest of the euro area is very substantial, it amplifies the initial shocks by 15-28% (see chart 1). And the main finding of this exercise is that the degree of interconnectedness influences the amplification of initial shocks. This happens in two steps. First, a hundred-euro GDP loss in Germany in this scenario causes a 13.5 euro loss in the rest of the Euro Area through supply linkages (see figure 1 and A.5 left-side maps). Lost output reduce income if the original shock is not counteracted through public support measures. Then, the income shock triggers an equally-sized demand shock that is distributed homogeneously across expenditure components, domestic and foreign production and the euro area GDP contracts by another 8.6 euros (see charts 1 and A.5 right-side maps).

When individual countries and sectors are examined, a few patterns become visible. The Benelux countries are among the most severely affected from transmission in all cases, given their openness and their geographic location, their specialisation in complementary services to manufacturing and their strong ties with the big 5 economies. The exercise also confirms the importance of the neighbouring countries, with Portugal being the most affected via consumption and production ties from a shock in Spain. Coke, petroleum and fuel is among the most severely affected sectors in almost all cases of deterioration of

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[6]we rely on ECB internal analysis conducted by country desks on sectoral repercussions from COVID-19 suppression measures at the ECB

[7]See the box entitled "Alternative scenarios for the impact of the COVID-19 pandemic on economic activity in the euro area", Economic Bulletin, Issue 3, ECB, 2020.

economic activity because of transversal contribution to any other sectors. Furthermore, the most affected industries from the supply shock are those a country specialise in; this is the case of transport equipment for Germany, footwear and textile production in Italy, and the tourism industry in Spain.

The euro area foreign trade contracts more than aggregate activity and lockdown measures lead to GVC retrenchments. The COVID-19 induced shocks bring up a deterioration of euro area member states net trade position. Net trade contracts in all big five euro area economies, substantially contributing to the transmission of the initial domestic shock to GDP. We find that the deterioration is greatest for most open countries, those running large trade surpluses and when economies are deeply intertwined with shocked countries (the Netherlands and Germany).

Figure 1: Maps of shocks transmission in Germany, France and Italy through supply and demand linkages to the EA *(effects on GDP as a percentage of shocks in the originating country)*
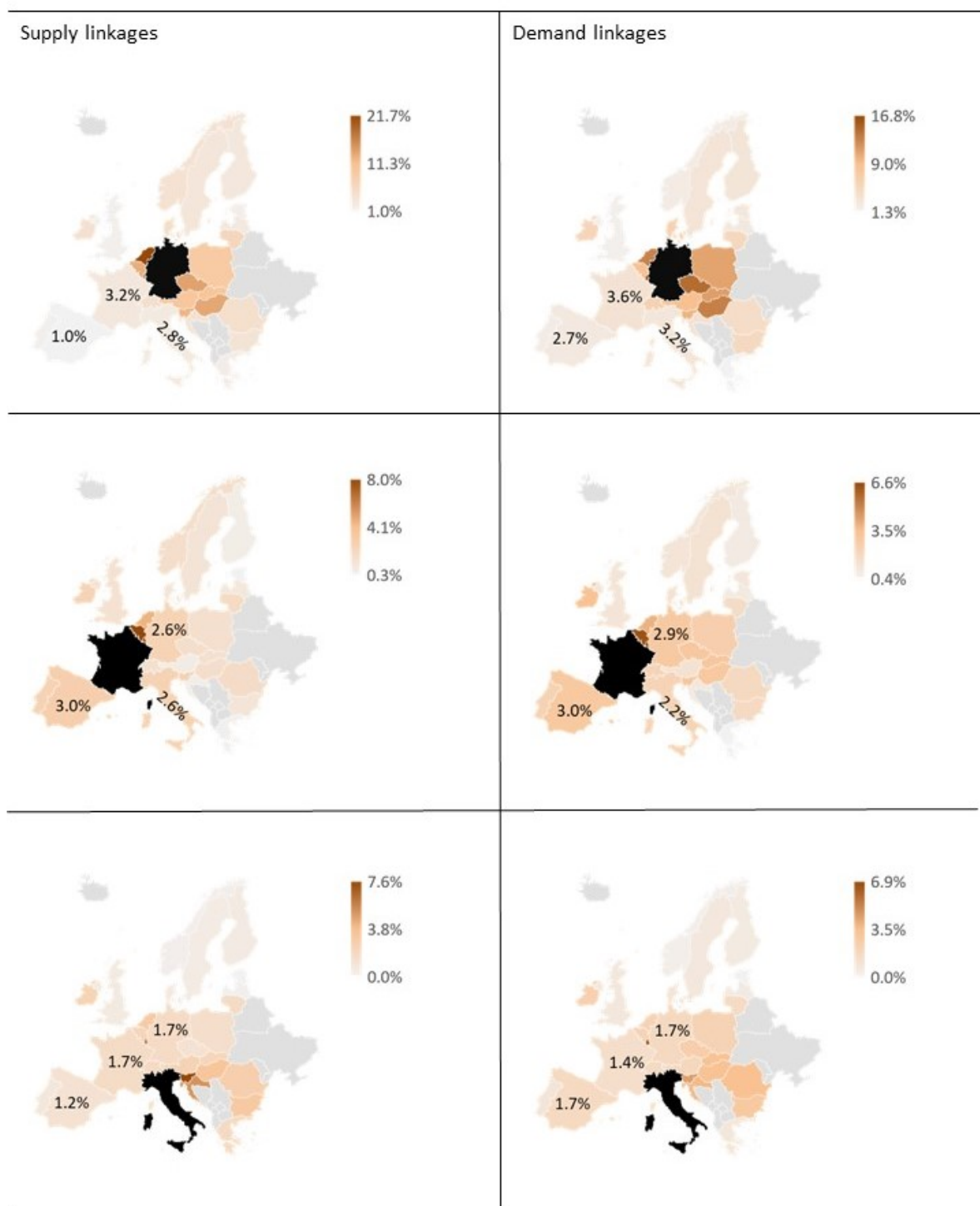
Sources: MRIO, authors' calculations.

Note: Transmission charts for Spain and the Netherlands can be found in the appendix in figure 6. To illustrate, a 3.2% transmission through supply linkages from Germany to France means that a 10% shock to German production gives a negative growth contribution of 0.32% to France through intermediate shortages.

3 The effects of lockdowns in the rest of the world on the euro area economy

The rapid unfolding of the crisis mirrored the virus spreading around the globe with lockdown measures adopted by an increasing number of countries outside the euro area. The euro area foreign demand weakened substantially, calling for an extension of our focus beyond domestic originated shocks. We quantify the fallouts on the euro area economy from a foreign demand shock triggered by suppression measures of COVID-19 in the rest of the world. First, we compare vintages of GDP forecasts for 2020 released just before and during pandemic and calibrate the foreign demand shock based on revisions to the expected growth of extra euro area economies owing to containment measures.[8]

Our estimates point to an initial decline in euro area foreign demand in 2020 as large as 10% and a contraction in euro area GDP by 2% as a consequence.[9]

Thereby the transmission of weaker foreign demand on the euro area GDP is about 20% the size of the original shock; this is in line with the share of domestic value added exported by the euro area to the rest of the world in 2018 (about 18%). In this scenario the direct effects on euro area economies are due to lower exports of final products to the rest of the world. Output in the euro area adjusts to lower exports and the demand for intermediates by euro area producers, both from within and outside the region contracts as well. Therefore, the proper regional supply chain transmission mechanism is triggered in a second stage and contributes about a fourth to the propagation of the foreign demand shock within the area.

Among euro area countries small, open economies are the most affected by the foreign shock. And in this subset the eastern euro area economies exhibit the strongest indirect effects from supply chain disruptions (see figure 2). However the contribution of the largest five economies to the overall effect on euro area GDP remains dominant. It represents more than 80% of the total direct impact due to lower extra euro area exports as well as of the indirect effects due to the euro area supply network. The Netherlands and Germany, owing to their downstream position within the euro area supply chain which make them closer to extra euro area final demand, are more affected than France, Italy and Spain (see Chart 3).

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[8]We use the International Monetary Fund predictions on GDP in 2020 of the World Economic Outlook, released in July 2020.

[9]The size and the distribution of sectoral shocks are entirely determined by the ICIOT structure; the more sectoral output is used in foreign production processes or consumed outside the euro area, the heavier the repercussions for that industry. This framework does not accommodate scenarios when foreign demand for some specific products weakens particularly. The evident case of tourism is separately evaluated in section 4.

Figure 2: Ranking of countries by the most to the least (direct and indirectly) by a negative shock to the euro area foreign demand (as a % of the original shock
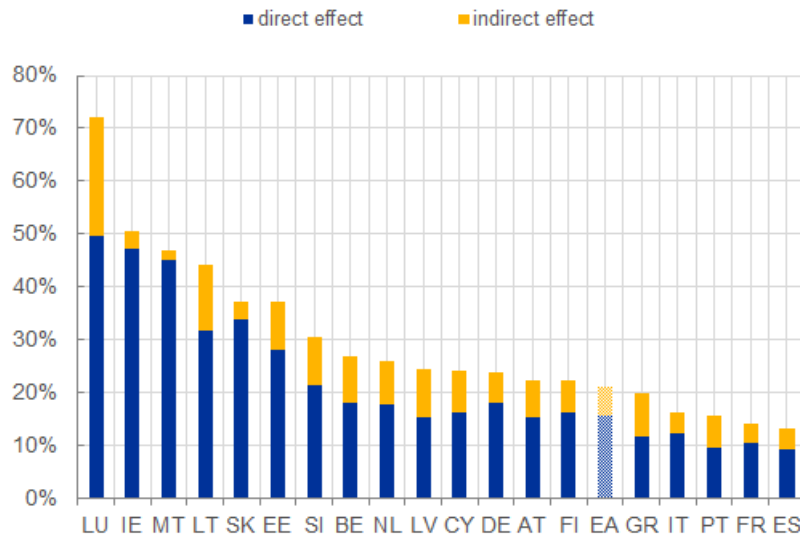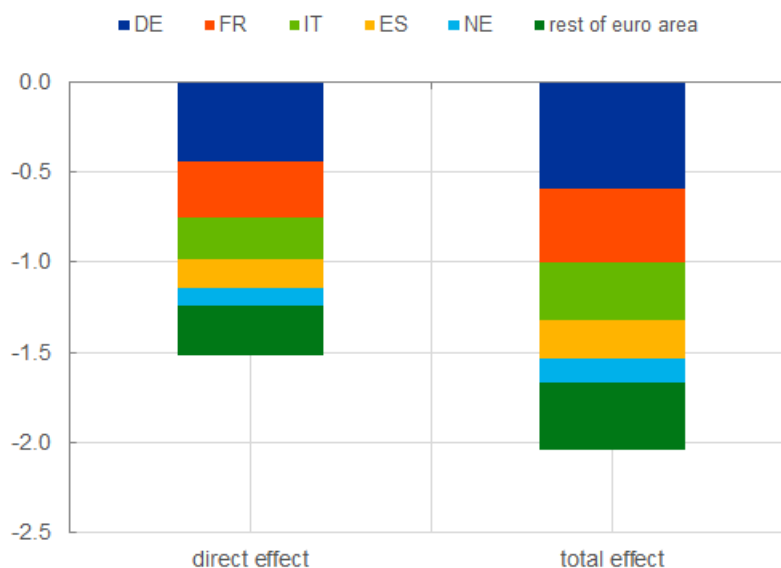

Source: MRIO, authors' calculations.Note: the calibration of foreign demand shock is based on July 2020 IMF (World Economic Outlook) predictions of GDP in 2020 and aggregated with weighted by bilateral share of each country in total extra EA exports (-9.7%). Luxembourg, the most exposed EA country, suffer a contraction in its aggregate activity equal to 70% the size of the original shock, about a third of it is due to indirect, internal EA supply linkages.

This exercise, when compared to the evaluation in section 2 highlights that different shocks use different transmission channels with consequences on the income elasticity of trade and euro area trade composition. The exported domestic value added performs poorly relative to total trade when demand shocks originate in the rest of the world. Gross exports decline almost four times the GDP, especially non GVC exports whereas supply disruptions within the area have more severe implications for GVC trade. This reflects the fact that the share of domestic value added in extra euro area exports is almost twice as large as that of intra euro area trade.[10] Thereby, this result is warranted by the complexity of euro area production network.

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[10]The definition of GVC trade refers to flows crossing at least two borders, see Borin and Mancini (2015).

Figure 3: The effect of a negative foreign shock on the EA aggregate activity (percentage points)

Source: MRIO, authors' calculations. Note: the calibration of foreign demand shocks are based on January and July 2020 IMF (World Economic Outlook) predictions of GDP in 2020 and aggregated weighting single country shock by their bilateral share in total extra EA exports.

4   Re-opening the Schengen borders - the rediscovery of recreation and travelling in Europe

Free movement of people remains a European Union milestone. Regional tourism is as relevant as domestic tourism in a number of euro area members, for less touristic European countries the majority of night stays occurs outside national borders but within the EU.[11]

We study the effectiveness of euro countries regional and internal borders reopening in softening the impact of containment measures on hospitality, travel and transports. In particular we compare a hypothetical extreme scenario in which global lockdowns were to be prolonged until the end of 2020 with the current conditions of easier domestic mobility and European selective borders reopening, depending on the ability of single countries to keep the contagion under control.

Transports, hospitality and food services are the hardest hit from pandemic as lockdown measures have paralysed the activity in these industries in a first moment. International organisations estimated a yearly contraction of global revenues in these sectors between 30-35%.[12]

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[11]In OECD economies instead domestic tourism makes on average the three quarters of the sector business volumes.

[12]International tourists arrival contracted globally by 22% in Q1 and the expected decline by the world tourism organisation for 2020 ranges between 60 and 80%. According to the international air transport

According to the European Commission, air, land, sea transportation, food services and accommodation contribute directly and indirectly, on average almost 10% of EU GDP. In the euro area tourism and related sectors are an important source of income in several countries where the positive net trade position sizeably contributes to the GDP growth. They make up nearly 20% of GDP in Croatia, 13% in Greece, almost 10% in Spain, 8% in Portugal and above 7% in Italy. For Greece they reach up to 30% of exports (the bulk is sea transportation services).

We calibrate shocks based on the central prediction of world tourism organisation on tourism business volumes in 2020 and apply a uniform adverse shock of -35% on annual basis to food and accommodation and to air and sea transportation while we assume that land transport volumes of activity is reduced by 20%. The shock to this sector is scaled down to reflect the fact that land transports includes also transport of goods and people mobility within domestic borders, which are not as concerned by containment measures. The advantage of resorting to inter country input output tables for this type of assessment is that they fully incorporate the heterogeneity existing across countries exports and imports in domestic, regional and extra-regional tourism and travel. There is hence no need to assume differentiated patterns beside a credible calibration of adverse shocks. A standing limitation is that the exercise cannot disentangle hospitality and travels for business and for vacation, thereby they are treated uniformly.

Protracting strict travel bans, complete closure of accommodation and food services everywhere, would have resulted in an adverse shock on EA GDP by 1.7 p.p. on annual basis. Domestic and international linkages would have amplified the contraction of euro area GDP by about a third. Euro area gross exports of goods and services would have contracted 20% more than aggregate activity and supply chain trade, the least resilient component, would have fallen 1.5 times the GDP. Furthermore since the euro area is home of world renowned touristic sites and regularly hosts more tourists from the rest of the world than Europeans travels outside the euro area, exports would have been affected to a greater extent than imports. Our analysis points out that 40% of the amplification of the original shocks on aggregate activity can be accounted by the net trade deterioration.

association, air passenger collapsed in April globally, surviving only on essential business travels, with very marginal improvements in May entirely due to domestic flights. In the EU the number of nights spent in tourist accommodation establishments declined by 44% from January to April 2020, compared to the previous year. The most substantial falls were recorded in March (-62%) and April (-95%) compared with the same months of 2019 and reverted the positive trend in January and February.

Figure 4: The multipliers of global travel and tourism ban measures
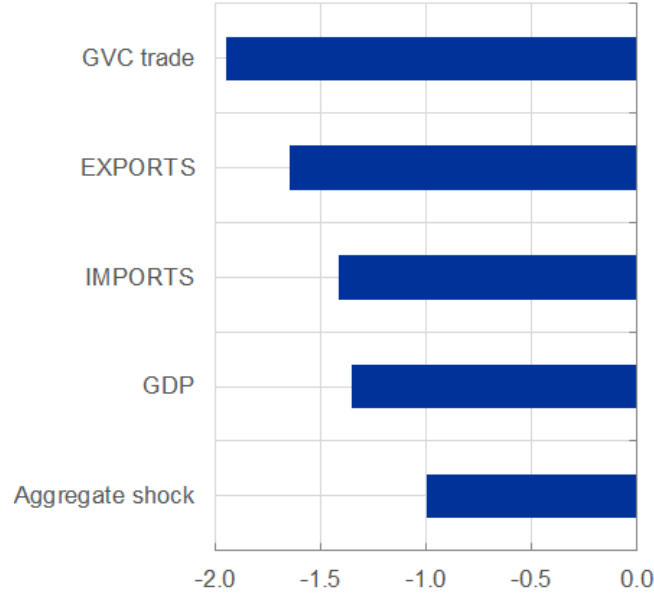
Source: MRIO, authors' calculations. Notes: Multipliers indicate the percentage changes in GDP and in EA trade as a consequence of a one percent global shock concerning travel, tourism accommodation and food services activities.

The European wide decision to reopen the Schengen borders, gradually as of June, has likely reduced very substantially the negative consequences from protracted immobility in 2020. Despite reopening, the introduced distancing measures have anyhow slashed transport, accommodation and restaurants capacity loosely by a half; moreover travel bans remained in place outside Europe. We embed differentiated sectoral shocks across origin-destination pairs in our work-horse; intra-regional shocks are now half their initial size whereas the magnitude of shocks concerning extra euro area countries is unaltered.

The beneficial effects of reopening differ across countries depending on their exposure to foreign tourism and the contribution of sectors under analysis to GDP. Country repercussions are shown in figure 4 as a percentage of the largest impacted country, e.g. Greece where the lost GDP would be highest (-7.1%), this value is set equal to 100, others are indexed accordingly.

Adverse repercussions on euro area GDP are contained by more than a third as a consequence of improved mobility domestically and within Europe. The overall contraction is reduced to 1.5% of EA GDP from 2.3%; as expected, euro area touristic destinations benefited proportionally more. Greece and Portugal regained several p.p. of GDP, however the size of contraction remains very large (see figure 5). In relative terms the negative effects on Portuguese GDP are about 60% those in Greece and on Italy's GDP just a third. If euro area countries are instead ranked by the percentage of contraction that could be unwound with border re-opening, Austria is the country enjoying greatest benefits from reopening

with 51% of adverse effects removed, Italy is second with 46% (see also the appendix A.4, figure 7 for country by country point estimates). The positive effect on total exports is even larger with two thirds of the negative impact avoided.

Figure 5: The effect of global bans to travel and tourism and the re-opening of Schengen borders in the second half of 2020
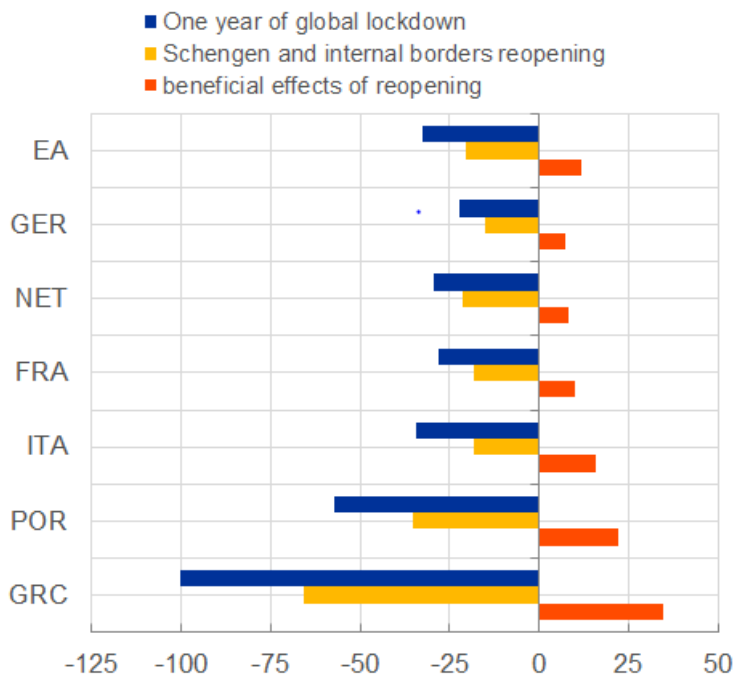
Source: MRIO, authors' calculations. Note: Blue bars show the effects of tourism and travel bans protracted for one year globally, yellow bars the case of Schengen borders and hospitality places re-opening. The benefits from easing the restrictions are reported relative to the most negatively affected country (e.g. Greece).

Sector-wise upstream industries that provide several inputs just to the sectors concerned by the lock-down have benefited the most from regained mobility, they are refined oil products, food, beverages and tobacco manufacturing industries as well as fishing and aquaculture.

5 Rethinking GVCs

The outbreak of COVID-19 raised the question whether the GVC production model rather than representing a competitive hedge has shown its limits during the pandemic (see Golgeci, Yildiz and Andersson (2020)). By exposing countries that participate in international production network to several adverse events, GVCs are channels of shock diffusion and yet reshoring outsourced components and tasks does not represent a solution. Relying less on foreign inputs and more on domestic production leaves economies more exposed to idiosyncratic shocks originated at home; less diversification across sources heightens the

consequences of supply disruptions on GDP and do not reduce the likelihood of their oc-currence. Moreover replacing the most efficient producers worldwide with the most efficient at home, rises production costs and likely funnels higher consumption prices.

Recent OECD analysis concludes that localised regimes, where economies are not inter-connected via GVCs, bring significantly lower levels of economic activity and lower incomes; furthermore greater localisation fails to deliver more protection from foreign shocks because of increased dependence on fewer and more expensive input sources, thereby reshoring poli-cies fail twice (see OECD (2020b),OECD (2020d) for details).[13]

Furthermore from a financial perspective, production networks represent a safety net for participating companies in times of crises. During a crisis, the weakest links in the network may be rescued, merged or acquired, the financial holding of large groups can provide liquidity avoiding credit crunches; financing difficulties can also be relaxed by temporarily relying on more favourable payment conditions of suppliers in the network. In their absence, firms will rely more on external sources and economies endowed with strong and advanced financial system would have a comparative advantages on the others.

Finally in cases of production curtailments, firms in the network will receive preferential treatments over others and be the last to experience shortages of intermediate supplies; to such extent activity within network may prove more resilient to heightened risks of disruptions.

However the safety net helps mainly to overcome temporary setbacks but it will not handle strained companies over medium term; it remains hence a prerogative of governments to avoid long term scarring effects from the pandemic.

Are there viable alternatives to excessive reliance on traditional GVCs? Can govern-ments and institutions enhance economies' resilience when production is organised in com-plex chains? It is not yet clear how public interventions can best alter market-determined outcomes, however considerations of this kind shall go beyond the sheer economic conve-nience and seek social welfare maximization (see also OECD (2020a)).

International cooperation can be strengthened to warrant that no country faces again shortages of essential products, like medicine and medical appliances, by reducing excessive production concentration of key components in single factories and allowing more geographi-cal diversification. Higher production costs and inefficiency would ensue from customisation as economies of scale are not optimally exploited. Agreements among companies for rapid conversion of assembly lines during crises would probably require governments to play a coordination role. The build-up of inventories attenuates risks of curtailment but it is costly and wasteful as goods are perishable and volatile demand requires a "just-in-time" production model in some industries.

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[13]In order to provide an answer, grounded on quantitative analysis to the question whether there may be some good in policies aiming to relocate production domestically, the OECD has recently used its large-scale METRO model and simulated a localised regime versus a interconnected regime.

In conclusion, partial solutions can be envisaged but they are not panacea; some call for a coordination role of institutions and they all entail extra costs.

6   Conclusions

This note analyses how domestic and foreign adverse shocks generated by containment measures are transmitted and magnified within the euro area. International country-sector interconnectedness and openness determine the strength of shocks propagation via foreign trade but our analysis has shown that the amplification effects and the transmission channels vary depending on the type of shock.

The propagation in the euro area is strong because the region is a typical example of diffused factory with strong final demand linkages. The transmission to the rest of the euro area of a shock originated in one of the five largest member countries ranges between 15 and 28%. A common or coordinated response through targeted fiscal and monetary measures is in the self-interest of EA countries to minimize the feedback loop effects of COVID-19 induced shocks in individual member states on the entire euro area. The European Commission recovery fund and the ECB extraordinary monetary measures address this necessity.

Foreign demand weakness depresses aggregate activity of the euro area by about a fifth the size of the foreign shock. A quarter of this effect is due to transmission of lower intermediate and final goods demand within the area. The most open EA economies remain especially exposed to extra-EA developments, even when COVID-19 spreading is under control in the euro area and a normalisation of economic conditions is underway. Thereby, stimulating domestic demand is advisable also in response to subdued foreign demand.

While tourism from the rest of the world remains blocked, reopening the Schengen borders significantly reduces the economic damages to touristic EA destinations that often suffer also from structural economic fragilities. Caution remains highly advisable and the community should react in a concerted manner to local hotspots, for instance by setting temporary restrictions to free movement if certain infection thresholds are exceeded.

Significant changes are occurring in our life styles and how we spend our working and leisure time that this note does not discuss. COVID-19 accelerated transformations that were underway; today and in a foreseeable future we will live in a world characterised by remote or distanced work, teleconferencing, reduced assemblies in public and work places and any means of transport, controlled tourism, less mobility and travel. Inevitably all this will have permanent repercussions on the structure of economies and their production systems.

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A   Appendix

A.1   The working tool: the inter-country input output tables

The analysis takes data from the Multi-Regional Input-Output (MRIO) database of the Asian Development Bank (ADB) that reconstructs national and international flows between country-sector pairs, as well as sectoral final demand. The database encompasses all euro area economies and a broad set of other countries. Compared with alternative sources, it also provides more recent information up to 2018. [14]

The analysis uses a static representation of the economic linkages across sectors and countries to evaluate the economic effects on individual industries of virus-suppression policies. Different sectors are affected to a different extent by supply disruptions and lockdown measures. The entire manufacturing industry, except for food, beverages, tobacco and pharmaceuticals, has been significantly affected by COVID-19 containment measures. Repercussions on agriculture and aquaculture have been less severe, as is the case for certain services that can be provided remotely, such as telecommunications that may even have received a boost as a result of changing behaviour of economic agents during pandemic. Conversely, other areas, namely transport, tourism and accommodation, are assumed to have experienced the severest adverse hits. We account for this through the careful differentiation of production shocks.

An ICIOT (see Table A) is structured around two main matrices: the international market for intermediates, Z, and the international market for final goods, Y. The rows of Z are producing country-sectors and the columns are consuming country-sectors. The columns of Y are pairs of countries and final demand sectors (such as private consumption and investment), only one of which is depicted in the simplified illustration below. Both Y and Z consist of G times G sub-matrices that contain the bilateral sectoral supply linkages between all country pairs.

A number of aggregate and more granular descriptive statistics can be obtained from the ICIOTs. This is illustrated below by some examples. Let z_{ijst},y_{ijs}, x_{is},va_{is} denote the elements of the respective matrices, where s, t $\{1,\ldots,N\}$ denote the exporting and the importing sector respectively. The sectoral value added for country 1 is then calculated for each sector as total output minus intermediate input,

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[14]The conclusions of our empirical assessments have been cross-checked using the world input-output tables (WIOT) in the World Input-Output Database (WIOD), an alternative source of inter-country sector linkages that includes 45 countries and spans 56 sectors but contains outdated information (the latest data are from 2014). The WIOD is a European Commission-financed project developed by a consortium of universities and research institutes and it covers the years 2000-2014. The MRIO database expands on the WIOD along two main dimensions – it extends the tables to include more recent data (the latest are from 2019) and several additional Asian economies. However, it features a more limited number of sectors (35 versus 56 in the WIOD) as service activities are defined.

Table 1: Structure of inter-country input-output table with G countries and N sectors

		Outputs				Final demand				Total output
		1	2	...	G	1	2	...	G	
Inputs	1	Z11	Z12	...	Z1G	Y11	Y12	...	Y1G	X1
	2	Z21		...	Z2G	Y21		...	Y2G	X2
	...	...	...	...	...	...	...	...	...	...
	G	ZG1	ZG2	...	ZGG	YG1	YG2	...	YGG	XG
Value added		VA1	VA2	...	VAG					
Total output		(X1)'	(X2)'	...	(XG)'					

Note: Z_{ij} is the NxN matrix of intermediate inputs produced in country $i \in \{1,\ldots,G\}$ and consumed in country $j \in \{1,\ldots,G\}$. VA_i is the 1xN vector of value generated in country $i \in \{1,\ldots,G\}$. X_i is the Nx1 vector of gross output produced in country $i \in \{1,\ldots,G\}$. Y_{ij} is the Nx1 vector of final goods and services completed in country i and absorbed in country $j \in \{1,\ldots,G\}$.

$$va_{1\sigma} = x_{1\sigma} - \sum_{i=1}^{G}\sum_{s=1}^{N} z_{i1s\sigma} = \sum_{j=1}^{G}\sum_{t=1}^{N} z_{1j\sigma t} + \sum_{j=1}^{G} y_{1j\sigma} - \sum_{i=1}^{G}\sum_{s=1}^{N} z_{i1s\sigma} \ \forall \sigma \in \{1,\ldots,N\}. \quad (1)$$

Sectoral exports of country 1 are total sectoral output minus sectoral output consumed on the domestic intermediate and final market,

$$exp_{1\sigma} = \sum_{j=1}^{G}\sum_{t=1}^{N} z_{1j\sigma t} + \sum_{j=1}^{G} y_{1j\sigma} - \sum_{t=1}^{N} z_{11\sigma t} - y_{11\sigma} \ \forall \sigma \in \{1,\ldots,N\}; \quad (2)$$

while sectoral imports are total intermediate inputs plus final demand produced by the sector minus intermediate and final consumption originating from domestic sectoral production,

$$imp_{1\sigma} = \sum_{i=1}^{G}\sum_{t=1}^{N} z_{i1\sigma t} + \sum_{i=1}^{G} y_{i1\sigma} - \sum_{t=1}^{N} z_{11\sigma t} - y_{11\sigma} \ \forall \sigma \in \{1,\ldots,N\}. \quad (3)$$

The sum across sectors of (1), (2) and (3) yields respectively the GDP, total export values and total import values of country 1.

We apply sectoral supply shocks to rows and demand shocks to columns. Shocks are calibrated based on internal and external analyses of the repercussions of countries' containment measures.[15]

Depending on the scenario, shocks (s) can be unilateral or multilateral and model pro-

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[15]These assessments consider the effects of fiscal and monetary measures on sectors' activity and countries' GDP. Therefore, while we do not explicitly evaluate the effects of policy measures, we indirectly take their effects into account in the shock calibration.

duction disruptions or final demand shocks. The ICIOT (Z* Y*) including production shock is obtained by multiplying the rows of the affected matrices rows by the Nx1 shock vector s (e.g. Z_{ij}*=Z_{ij} ⊗s1', where ⊗ is the Hadamard product) and the ICIOT including the demand shock by multiplying the columns of the affected matrices by the transposed shock vector (e.g. Z_{ij}*=Z_{ij} ⊗ 1s'). The impact of each shock on euro area activity and foreign trade is the difference between the values obtained from the pre-shock ICIOT and the post-shock ICIOT. [16] In a second stage, indirect shocks are applied to model the supply chain adjustment to the shock in the first stage. Their calibration is a function of the initial shock, the WIOT structure and an additional assumption on the elasticity of output with respect to intermediates, which is discussed below. The economic mechanism is explained in Section 2.1.

There is, however, a caveat to this approach, which concerns the treatment of shock vector intersections. Take, for instance, a unilateral shock to economy c affecting all sectors differently. The linkage $Z_{cc}(1,2)$, i.e. the intermediate inputs of country c sector 1 to country c sector 2, could be reduced either by the production shock in sector 1 or by the intermediate demand shock of sector 2. In these situations, we assume that equilibrium is determined by supply, which means that the production shocks are the initial triggers and do not account for further fallout on the activity of sector 1 due to lower intermediate demand from sector 2. [17]

An important simplifying assumption made in our approach is that a production shock in one country-sector pair triggers an equivalent intermediate demand shock and vice versa. Our strict proportionality assumption is akin to assuming that the base reproduction number (r0) is equal to unity and constant over time, hence each additional shock will always have a similar effect on the economy.[18] This is nevertheless a simplification since, in this rapidly changing reality, the dynamics of propagation of a shock through foreign trade are similar to those of the spread of a virus and the contagion rate in the economic "epidemic" process rises rapidly in the early stages when few sectors and economies are infected. In the very short run, key components and crucial services that suddenly cannot be delivered anymore can paralyse entire production chains, but contagion progressively flattens and abates as more and more economies are hit.

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[16]Pre- and post-shock values of economic statistics were obtained through ICIO, a built-in tool in Stata; see Belotti, F., Borin, A. and Mancini, M., "icio: Economic Analysis with Inter-Country Input-Output Tables in Stata", Policy Research Working Paper No 9156, World Bank, Washington DC, February 2020.

[17]As a result, the production shock is not exactly equal to the value-added shock, there are small differences; according to our computations, such discrepancies are of a two-decimal order of magnitude. Moreover, this concerns sector spillover effects in the domestic market whereas the article focuses on the international transmission of idiosyncratic shocks, which is not affected.

[18]In the extreme scenario, when no substitution across inputs, sources or final destinations is possible in the production process, the entire supply network is already disrupted by the first shock; in a situation of this kind, r0 goes to infinite but then falls rapidly to zero for any subsequent shock.

A.2　The calibration of sectoral shocks

In our framework, as long as the relative magnitude of sectoral innovations is preserved, the final effects of a given shock is proportional to the original shock. Due to the linearity of our model, shock effects on macroeconomic variables can be scaled up or down if the sectoral distribution (in a unilateral shock) or inter-country relative distribution (in a multi country shock) remains the same. This way, our assessments can be adapted to analyse the effects of milder or more severe trajectories that the pandemic might take. Sectoral shocks are reported as percentages of the largest shock. Thus, the industry experiencing the sharpest contraction in production takes the value of 100 and shocks in other sectors are indexed to it. We calibrate the shocks based on sectoral information available on the effects of suppression measures from country experts at the ECB. The shock to weighted aggregate activity in each country is set equal to the GDP contraction projected in the June 2020 Broad Macroeconomic Projection Exercise (BMPE).

Table 2: Shock calibration. Indices of sectoral output shocks due to containment measures by main sector of activity

Sector	Germany	France	Italy	Spain	The Netherlands
Agriculture	25.0	6.2	25.0	15.0	25.0
Industry (excluding manufacturing and construction)	75.0	9.9	75.0	15.0	75.0
Manufacturing	75.0	35.8	75.0	31.3	75.0
Construction	75.0	100.0	75.0	73.1	75.0
Retail trade, transport, accommodation and food service activities	100.0	64.2	100.0	98.5	100.0
Private services	47.5	22.1	25.0	41.5	51.6
Public administration	25.0	18.5	25.0	-3.0	25.0
Arts, entertainment, recreation and other activities	75.0	70.4	75.0	100.0	75.0

Source: ECB staff calculations. Note: The shock in the most severely hit sector resulting from containment measures is indexed to 100, shocks in the other sectors are a percentage of this. Private services include several activities: information and communication, financial and insurance activities, real estate activities and professional, scientific, administrative and technical activities.

Possible trade diversion effects are ignored as their appearance may be delayed and our analysis focuses on 2020. The assumption of non-substitutability of supply and demand (e.g. lower exports by a country will not be replaced by other countries' exports) across origins and destinations is strong, draws on the idea that, as with viruses, immunisation from shocks disrupting global value chains (GVCs) requires time. It may entail, for instance,

starting new lines of production or diverting demand to other suppliers, which may prove to be imperfect substitutes as a result of limited supply capacity or other factors.

A.3   Tansmission Channels

Various channels can be at work when shocks spill from origin country-sectors to the rest of the world, amplified by foreign trade. In particular domestic production shocks are transmitted to upstream and downstream trading partners and further up and down the chain to partners of trading partners via export and import. Intuitively, by halting domestic production, lockdown measures are conducive to shortages of intermediate goods produced domestically that enter foreign production processes via trading partners (export channel). Thereby, these generate negative supply shocks for companies located downstream in the chain. At the same time, these reduce the demand for foreign intermediates entering domestic production processes (import channel). The closure of businesses also results in a negative demand shock for companies located upstream in the production process relative to the original locked-down businesses. To the extent that intermediates cannot be substituted, the entire foreign production line is hampered and, as a consequence, purchases of intermediates from any other country are also proportionately slashed. The operation of the export channel propagates initial supply shocks further down the chain. Likewise, lower import demand for foreign intermediates depresses not only their production in partner economies, but also in other countries that supply inputs for the same processes. The import channel hence operates indirectly on all companies upstream. Besides intermediate-production linkages, lockdown measures also reduce exports of final products, hence constraining consumption possibilities and potentially generating unintended and temporary extra savings.

Final demand shocks are only transmitted up the value chain; negative ones directly diminish imports, which then leads to a reduction in the production in other countries, unless firms replace them with exports to other destinations; this in turn decreases their demand for intermediates.[19]

To illustrate the transmission mechanism, let us consider shop closures and, more specifically, look at the case of a bar forced to lock down. Intuitively, if hypothetically the output of food and entertainment services goes down by 10% and these services account for 10% of GDP; such measures will have a direct negative effect on GDP of 1%. However, the bar will reduce its purchases of beer, which will have an impact on the revenues of beer producers which is equal to their share of the total costs of bars. If we assume this to be 20%, then an additional contraction of 0.2% in GDP will ensue. Looking further upstream in the

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[19]This process could be reiterated several times up the value chain. We, however, only model the first two steps, the reduction in imports and foreign production as well as the foreign intermediates demand shock. This is to account for the time lag that production adjustment needs, but also because the magnitude of indirect effects shrinks with each additional iteration.

beer production process, when beer sales wane, producers order and purchase fewer hops by an amount proportional to the share of hops in total costs. If this ingredient accounts for 25% of beer production costs, the GDP is shaved by a further 0.05%.The overall effect on the country GDP will be equal to -1.25% if the production chain is entirely domestic, while the negative impact is shared internationally if foreign companies participate in this supply process. Our analysis of spillover effects stops at hops, although it encompasses all the economic ties that the bar and the beer producers maintain with other sectors and economies.

A.4 Figures

Figure 6: Maps of transmission of shocks in Spain and the Netherlands through supply and demand linkages to the EA (Shock to GDP as a percentage of originating country shock
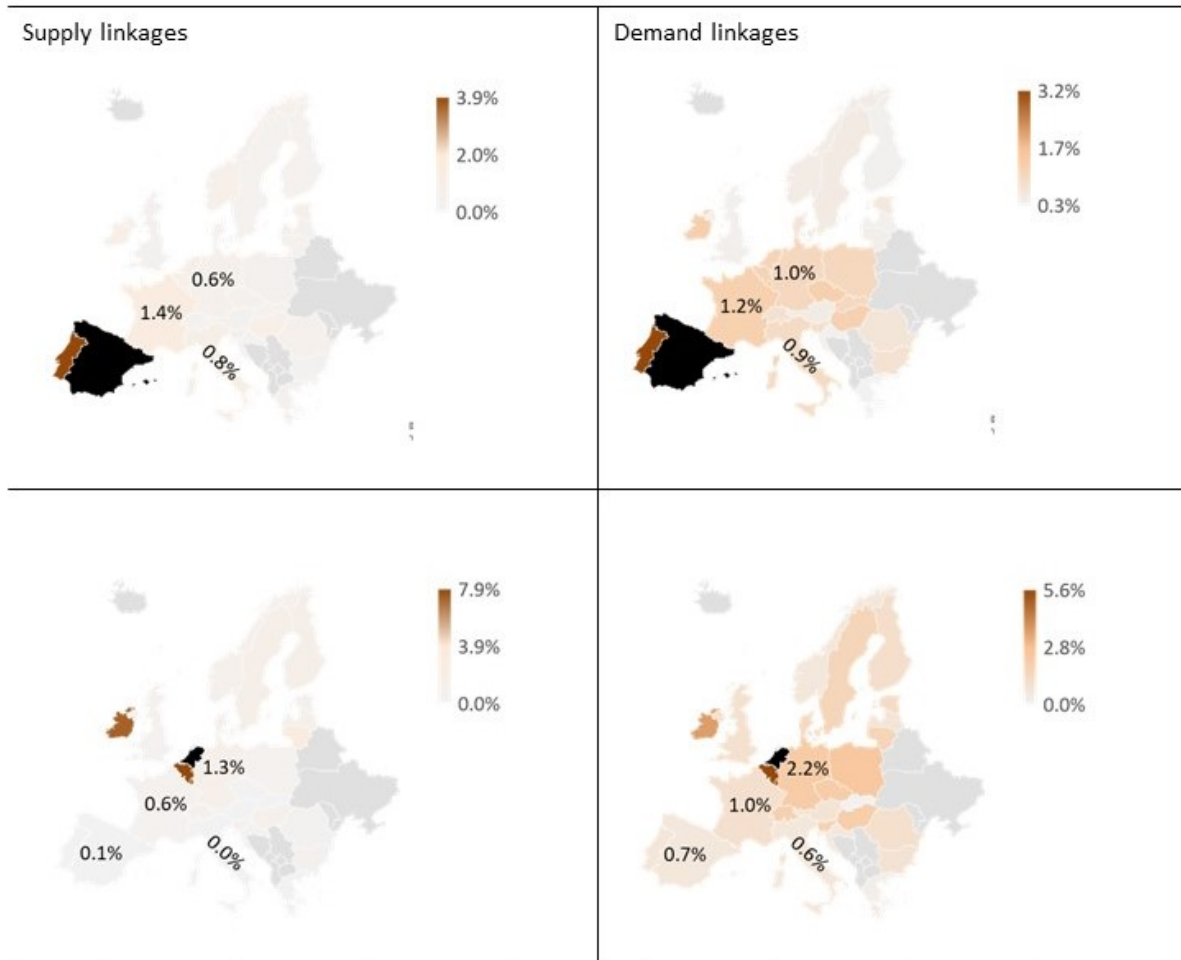
Sources: MRIO, authors' calculations. Note: to illustrate, a 1.4% transmission through supply linkages from Spain to France means that a 10% shock in Spain production gives a negative growth contribution of 0.14% to France through intermediate shortages and above 0.4% to Portugal.

Figure 7: Beneficial effects of reopening the Schengen borders to intra EU tourism
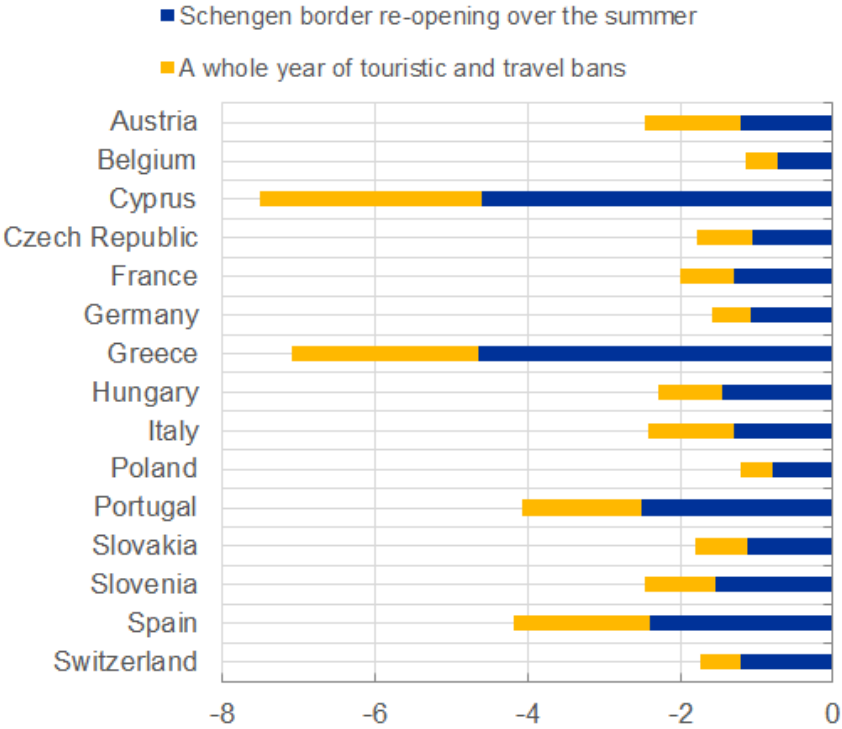
Sources: MRIO, authors' calculations. Note: The estimated negative effects on in 2020 GDP of travel and tourism bans as well as hospitality business closure for EU countries are shown by the blue bars; the yellow bars depict the additional negative effects for EA countries if Europe had not decided to gradually ease internal mobility restrictions from the summer.