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## Abstract

This paper analyses the aggregate impact of industry-specific shocks and their propagation through global production networks. We focus on the case in which a common shock affects simultaneously the same industry across different countries. Thus, our analysis can be a useful tool for several policy-relevant scenarios, such as changes in environmental regulations or the implementation of new technologies. For that purpose, we highlight the importance of departing from standard linear models that assume unitary elasticities of substitution. We combine a theoretical framework of production networks with arbitrary elasticities of substitution (Baqaee & Farhi, 2019) and we make use of World Input-Output Database to account for international linkages. This setting illustrates how, in the presence of production input complementarities, the interaction between simultaneous shocks has significant non-linear effects on sectoral composition and aggregate output. The aggregate impact of negative (positive) shocks gets significantly amplified (mitigated) when they affect simultaneously industries with strong production linkages. Our results show that ignoring production complementarities leads to vastly underestimating the aggregate consequences of regulatory or technological shocks in industries like chemicals or vehicle manufacturing. In contrast, simultaneous shocks to services industries are well accounted for by standard measures.

**Keywords:** input-output tables, networks, shock propagation.

**JEL classification:** F14, F15.

## Resumen

Este artículo analiza el efecto agregado de *shocks* sectoriales y su propagación a través de las cadenas globales de producción. En concreto, el foco se sitúa sobre un caso en el que un mismo *shock* afecta de manera simultánea a una misma industria situada en diversos países. Así, nuestro análisis puede ser una herramienta útil en varios escenarios relevantes para las políticas económicas, como cambios en la regulación medioambiental o la implantación de nuevas tecnologías.

Para ello, señalamos la necesidad de desviarse de los métodos tradicionales de análisis que asumen elasticidades de sustitución unitarias. Combinamos un marco teórico que permite valores discrecionales para las elasticidades de sustitución [Baqaee y Fahri (2019)] y utilizamos los datos de las Tablas Mundiales de *Input-Output (World Input-Output Database)* para cuantificar los vínculos internacionales entre sectores.

Este escenario ilustra cómo, en presencia de complementariedades de insumos de producción, la interacción entre *shocks* simultáneos tiene efectos no lineales significativos en la composición sectorial y en el producto agregado. El impacto agregado de los *shocks* negativos (positivos) se amplifica (mitiga) significativamente cuando afectan simultáneamente a industrias cuyos procesos productivos están fuertemente interrelacionados.

Así, nuestros resultados ponen de relieve que ignorar las complementariedades de producción lleva a subestimar enormemente las consecuencias agregadas de los *shocks* regulatorios o tecnológicos en industrias como la fabricación de vehículos o la producción de productos químicos. Por el contrario, los análisis estándar aproximan suficientemente bien el efecto en el caso de las industrias de servicios.



**Palabras clave:** tablas *input-output,* redes de producción, propagación de *shocks,* regulación industrial.

**Códigos JEL:** F14, F15.

# 1 Introduction

The pandemic-induced digitalization of services or the implementation of green regulations addressed to fight climate change are some of the topics gaining the most of policymakers' attention lately. A common feature of both cases is their highly asymmetric impact across sectors. Then, understanding the impact of such policies requires to understand the aggregate effect of industry-specific shocks. However, at the same time, another feature is that firms in any sector face very similar challenges independently of the country where they are located. Under these circumstances, a better understanding of the particular case in which a common shock affects simultaneously the same industry located in several countries is of paramount importance.

A basic fact to understand the propagation of sector-specific shocks is that economies consist of linked networks of industries. These industries rely on each other for their production processes. They purchase inputs from their suppliers and they sell their output to final consumers and other customer industries. Moreover, in open economies, those customers and suppliers are located both inside and outside a country's borders. For this reason, changes in an industry will propagate beyond its boundaries, starting with industries with which it has larger trading flows. For example, a negative shock to the Chinese manufacturers of electronic components will quickly reflect in the production of the German vehicle manufacturing industry, as long as the latter sources a large share of their inputs from the former. Thus, even if they originate at a particular corner, the aggregate consequences and propagation of industry-specific shocks will reflect the input-output structure of the economy.

However, industry-specific shocks can also reshape the input-output structure of the economy. Following the example above, vehicle manufacturers will try to substitute away Chinese electronic components with other suppliers. The size of these adjustments will be a direct result of the elasticity of substitution that producers and consumers have over different goods, and they will be larger when industry-specific shocks are sizable or they are correlated across industries with large trading flows. When the changes in trade flows among sectors are significant, the estimated effect of industry-specific shocks assuming the prior customer-supply links will be inconsistent. Still, this point is typically overlooked by standard network production models with unitary elasticities of substitution and invariant input-output structures.

We address a particular case of correlated industry-specific shocks, more precisely, a common shock affecting simultaneously the same industry across different countries. We discuss that in this case, the non-linear effects due to changes in the production networks can be particularly relevant. The reason stems from the large intra-industry trade flows existing in some industries. In many cases, producers of the same industry located in different countries have large trading flows among each other. Because of that, a shock affecting simultaneously to all of them will have implications for their own production but also the one of their main clients and suppliers. We provide an estimation of the aggregate impact that these shocks might have. We also discuss for which particular in-dustries the effect of the simultaneous shocks potentially far exceeds the sum of each of them considered separately.

Methodologically, we base our analysis upon the existing literature of production networks. More precisely, we rely on Baqaee & Farhi (2019). Their setting allows studying a flexible production network with arbitrary elasticities of substitution and the existence of a variety of industry-specific shocks. We make use of their framework to introduce our contribution. Using the World Input-Output Table (WIOT), we estimate the effect for the largest European economies of correlated industry shocks across countries. Our estimates can accommodate cases with different shock sizes as well as different sets of countries exposed to them. The latter exercise provides novel insights that are not yet documented in the literature. Typically, analyses of the aggregate impact of sector-specific shocks consider either sector-specific shocks in a particular country or country-specific productivity shocks affecting every industry.

Our work can be a useful tool for several policy-relevant scenarios. A practical example would be the implementation of new international environmental standards. This result is particularly relevant for European economies because it allows predicting the effects of productivity shocks linked to sector-specific supranational regulations, as in EU directives. The effect of Covid-induced digitalization in services would be another exam-ple that our setting can contribute to.

Our findings indicate that the aggregate impact of a negative TFP shock to manufacturing industries increases significantly when this shock is common to several countries. The difference between considering independent or correlated multi-country sector shocks

is larger in industries with highly integrated global value chains, as it is the case of European motor and airplane vehicle manufacturing or pharmaceutical industries. Conversely, this amplification effect is much more muted in the case of non-manufacturing industries

The paper is structured as follows. In **Section 2** we describe the theoretical framework that allows us to rationalize the mechanisms behind the propagation of sector-specific shocks through the worldwide economy. **Section 3** describes the I-O data and **Section 4** presents our main findings. Finally, **Section 5** provides some concluding considerations.

# 2 Conceptual framework

In this section, we outline a model of production networks based upon Baqaee & Farhi (2019) featuring both non-linearities and open economies. These elements are crucial to properly assess the international propagation of sector-specific shocks common to differ-ent countries via the global input-output network in the presence of different degrees of complementarities across sector-country pairs.

We proceed in three steps. **Section 2.2** shows the relationship between pairs of sectors. That is, the side effect for any given sector $j$ to a supply shock to sector $i$. **Section 2.3** shows the case of a demand shock to sector $i$. Once we have defined the propagation of shocks between pairs of industries, **Section 2.4** shows its aggregate footprint. This section shows that the effect of an industry-specific shock is proportional to the sales of the sector, what is known as its Domar weight. Finally, **Sections 2.4.1** and **2.4.2** combine the previous results and discuss how a shock to industry $i$ changes the sales of industry $j$ and, consequently, the effect that a simultaneous shock on the latter would have.

## 2.1 Production network

The environment is defined by a perfectly competitive economy consisting of $N$ sector-country pairs[1], each one producing a differentiated product. Crucially, we consider the same sector located in different countries as differentiated industries. This setting implicitly assumes that the elasticity of substitution between two outputs from different sectors faces the same elasticity between the goods from the same sector located in two different countries. We abstract from any other consideration related to international trade such as the existence of tariffs and transportation costs, as well as the role of exchange rate adjustments.

Each sector-country requires for production both labor, supplied by households, and intermediate inputs which could be produced by other sector-country pairs.[2] Producers combine intermediate inputs with a constant elasticity of substitution and produce under constant returns to scale. Turning to the consumption side of the economy, it is characterized by a representative household who supplies inelastically labor and has some preferences over the $N$ products, where $N$ is made up of each sector-country pair.

[1]Note that we refer to sector-country, sector or good indistinctly throughout the paper.

[2]We abstract from physical capital as an additional factor of production to facilitate the discussion. The main results also hold in the presence of capital input as discussed for instance in Acemoglu et al.(2016).

Formally, the production function in **equation** (1) and the utility function in **equa-tion** (3) fully characterize this economy as follows. Firms produce with the technology:

$$y_i \;=\; e^{z_i} l_i^{\alpha_i} \left( \sum_{j=1}^{N} \omega_{ij} x_{ij}^{\frac{\theta_i - 1}{\theta_i}} \right)^{(1-\alpha_i)\frac{\theta_i}{\theta_i - 1}} \tag{1}$$

where $l_i$ is the amount of labor hired by firms in country-sector $i$, $x_{ij}$ refers to the quantity of good $j$ used for production of good $i$, $\omega_{ij}$ is a non-negative technical weight of each intermediate input, and $z_i$ is a Hicks-neutral productivity shock. This setting implies that each sector operates under constant returns to scale. Finally, $\theta_i$ is the elasticity of substitution among different inputs. Crucially, this elasticity is allowed to be differ-ent from 1, which departs from the perfect substitability assumption in Cobb-Douglas, and it thus allows for the presence of complementarities or subtitutabilities across inputs.[3]

The non-negative weights $\omega_{ij}$ formalize the idea that firms in a sector may need to rely on the goods produced by other industries as intermediate inputs for production.[4] In particular, a larger $\omega_{ij}$ means that good $j$ is a more important input for the production of good $i$. Therefore, the notation implies that industry $j$ is the supplier and industry $i$ is the customer.

Note also that, in general, $\omega_{ij} \neq \omega_{ji}$, which is crucial for the differences in upstream and downstream propagation discussed below. Intuitively, country-industry $i$'s reliance on country-industry $j$ as an input-supplier is expected to be different from industry $j$'s dependence on $i$.[5]

Following profit maximization, the share of expenditure of a sector in each of the intermediate inputs is given by:

$$\frac{p_j x_{ij}}{p_i y_i} \;=\; (1-\alpha_i)\, \frac{p_j^{1-\theta_i} \omega_{ij}^{\theta_i}}{\sum_{h=1}^{N} p_h^{1-\theta_i} \omega_{ih}^{\theta_i}} \equiv a_{ij} \tag{2}$$

[3]There is a lack of consensus about the notation of supplier and consumer sectors in the literature. Many papers use the first subscript to refer the supplier sector while the second one for the customer industry. However, we prefer to follow the same notation that is used by our closest references, and we denote $x_{ij}$ as the flow of inputs that industry $i$ purchases from industry $j$.

[4]Without loss of generality, we assume $\sum_{j=1}^{N} \omega_{ij} = 1$ for every country-sector $i$.

[5]It may also be the case that $\omega_{ii} > 0$, as good $i$ may itself be used as an intermediate input for production by firms in industry $i$. Also, $\omega_{ij}$ might be equal to zero when sector-country pair $i$ do not use good $j$ as an input for production.

**Equation** (2) implies that the expenditure shares are endogenous to inputs' rela-tive prices. This will prove relevant when we discuss correlated shocks to different sectors: one sector's price will change after exogenous supply shocks and also will do its share of expenditure in the economy. In the edge case of Cobb-Douglas production function, optimality conditions imply $a_{ij} = (1 - \alpha_i)\omega_{ij}$.

The economy is populated by a representative household which supplies inelastically one unit of labor and gets utility from the consumption of the $N$ goods with a constant elasticity of substitution.

$$u(c_1, c_2, \ldots, c_n, l) = \left( \sum_{i=1}^{N} \omega_{ci} c_i^{\frac{\theta_0 - 1}{\theta_0}} \right)^{\frac{\theta_0}{\theta_0 - 1}} \tag{3}$$

where $\omega_{ci} \in (0, 1)$ refers to the weight of good $i$ in the utility function and $\theta_0$ is the elas-ticity of substitution among different goods. [6]

The equilibrium of this economy is defined as a set of prices and quantities such that the representative household maximizes her utility, the representative firm in each sector maximizes profits, and all markets clear. In particular, households decide the consumption bundle $(c_1, ..., c_n)$ by maximizing the utility function in (3) subject to the budget constraint $w - T = \sum_{i=1}^{n} p_i c_i$ for a given collection of prices $p_1, ..., p_n$ and the wage $w$. The representative firm in sector $i$ maximizes profits $(\pi_i = p_i y_i - w - \sum_{j=1}^{n} p_j x_{ij})$ and takes prices $p_1, ..., p_n$ and the wage $w$ as given. Finally, the market clearing condition implies that the output produced in each sector should be either used as intermediate input by other sectors or consumed by someone: $y_i = \sum_{j=1}^{n} x_{ji} + c_i + G_i$.

## 2.2 Propagation of supply shocks

The impact of a supply (productivity) shock to any given industry affects the entire economy due to a change in relative prices and it propagates through two channels. First, a productivity shock to any given industry $i$ changes its own price. In addition, it also changes the price of any other sector relying, directly or indirectly, on industry $i$ as an input supplier due to the change in costs. This first channel is purely downstream: it

[6] For practical reasons, in our computations, we consider households as an additional productive sector. In this equivalence, households from each country are productive sectors that assembles a final consumption good, $u$, combining as inputs the consumption of each variety, $c_i$, following (3). They combine inputs with an elasticity $\theta_0$ and they have a preference weight for each good $\omega_{ci}$. The main difference with respect to the rest of productive sectors is that we allow the elasticity of substitution to be different than the one of producers and that there is not a labor or productivity component in their function.

moves down from supplier to customer industries. Any productivity change to industry $i$ creates a cost change in that industry and it ripples out to any other industry that uses good $i$ as an input.

On top of that, there is an additional second channel that is a direct consequence of the change in relative prices described above. Following the change in relative costs, and depending on the the elasticity of substitution of industries and final consumers, there will be a reallocation of expenditure shares.

The elasticity between sector $i$ specific productivity shocks and the gross output of any sector $j$ is given, up to a first order approximation, by a downstream propagation effect and a substitution effect:

$$\frac{\mathrm{d}\ln y_j}{\mathrm{d}z_i} = \underbrace{h_{ji}}_{\text{Downstream propagation}} + \underbrace{\Theta_{ji}}_{\text{Substitution effect}} \tag{4}$$

The first element in (4) corresponds to the strictly downstream propagation effect, where $h_{ji}$ is the $(j, i)$ element the inverse-Leontief matrix, $H = (I - A)^{-1} = \sum_{r=1}^{\infty} A^r$.

The ($j$, $i$) entry of the Leontief matrix A represents the share of expenditure that sector $j$ has on industry $i$ as input supplier, as defined by (2). In other words, this is the *direct* importance of $i$ as a supplier of $j$. These values can be recovered directly from the input-output tables.

Therefore, each element of the inverse-Leontief matrix H can be expressed as $h_{ij} = a_{ij} + \sum_{r=1}^{n} a_{ir}a_{rj} + ....$ In other words, matrix H shows both the *direct* and *indirect* exposure of industry $j$ to industry $i$ through the production network. It is particularly relevant in our analysis that $h_{ij}$ also represents the elasticity between the prices of customer industry $j$ and supplier industry $i$.[7]

Intuitively, a positive productivity (supply) shock hitting industry $i$ leads to an increase in production $y_i$ and a reduction of price $p_i$. Customers of industry $i$ will demand higher quantities of good $i$ at lower prices.[8] Moreover, given lower inputs prices, the price of $i$'s customer industries will fall as well, creating an indirect positive effect on their own customer industries that propagates to the rest of the economy.

[7]Proof in Appendix A.1.

[8]Note that the traditional input-output literature also interprets this type of supply shocks as pure price-push shocks with no effect on quantities (see, for instance Oosterhaven (1996) or Dietzenbacher (1997)). This interpretation is based on a partial equilibrium approach that must rely on the assumption of perfectly price inelastic demand. In contrast, in the model described in this section, quantities do react to changes in prices in a general equilibrium setting, and thus, downstream propagation of supply shocks also implies real effects (see Proposition 1 in Acemoglu et al. (2012)).

Beyond strictly downstream effects, there are additional changes related to the substitution effect among goods. The second effect of a productivity shock (and the subsequent change in relative prices) is a reallocation of expenditure shares across different industries. Following the productivity shock, the change in relative prices meets a change in the expenditure of intermediate inputs and final goods when the elasticity of substitu-tion across varieties is non-unitary. For example, if intermediate inputs are complements in the production function and a positive productivity shock hits sector $i$, producers will reduce the expenditure share on those inputs more reliant in industry $i$ in favor of other goods. This implies that the propagation of supply shocks might not be exclusively down-stream. Instead, also the production of suppliers of the affected industry will change due to changes in the demand for different inputs.

In particular, the substitution effect in the demand of sector $j$ following a productivity shock to industry $i$ can be characterized as:

$$\Theta_{ji} = \sum_{s=1}^{N} \left( \frac{p_s y_s}{p_j y_j} \right) (\theta_s - 1) \cdot \left[ \sum_{z=1}^{N} a_{sz} h_{zj} h_{zi} - \left( \sum_{z=1}^{N} a_{sz} h_{zi} \right) \left( \sum_{z=1}^{N} a_{sz} h_{zj} \right) \right] \quad (5)$$

The intuition is simple.[9] Let's assume a negative productivity shock to sector $i$ and input complementarity in the production function, i.e. ($\theta_s < 1$). Following the negative shock to industry $i$, its price will rise and so will do the price of industries that rely on $i$ as input supplier. Thus, and given our complementarity assumption, any given sector $s$ will increase the expenditure share in those goods at the expense of the rest of industries. This reliance in industry $i$ as an input supplier is measured by the correlation between the $i$-th and $j$-th columns of matrix $H$ (term in brackets). These columns show how much the cost of any sector changes following a cost shock to industry $i$ or $j$ respectively. In other words, if an industry $j$ is heavily reliant on industry $i$, the exposure of other sectors to industry $j$ (measured by $j$-th column of H matrix) will be very correlated with their exposure to industry $i$ (measured by $i$-th column of matrix H). Finally, the reallocation is weighted by the size and complementarity strength of each sector $s$.[10]

## 2.3 Propagation of demand shocks

In the case of demand shocks, we analyze the change in production of sector $j$ following an exogenous change in consumption of any other industry $i$. To be more concrete, we explore a demand shock given by exogenous changes in the demand of product $i$ and included in the

[9] Appendix A.2 offers a formal derivation of equation (5).

[10] In the edge case of Cobb-Douglas technologies, productivity/supply shocks do not propagate upstream. The reason is that when $\theta_s = 1$, the change in quantities perfectly offsets the change in prices so the expenditure shares for each input remain constant.

model through the $G_i$ term in the market clearing condition. As in Acemoglu et al.(2016) we rationalize this type of demand shocks as country-sector-specific government consumption shocks in which government purchases $G_i$ are wasted or spent on goods households do not directly care about and financed by lump sum taxes ($T$ ) entering the households budget constraint above:

$$\frac{\mathrm{d}\ln y_j}{\mathrm{d}\tilde{G}_i} = \hat{h}_{ij} \tag{6}$$

where $\hat{h}_{ij}$ is the $(i, j)$ element of the upstream propagation matrix $\hat{H} \equiv (I - \hat{A})^{-1}$, and $d\tilde{G}_i$ is a demand shock expressed as percentage change in sales of the sector ($d\tilde{G}_i = d\frac{p_i \cdot G_i}{p_i \cdot y_i}$).

There are two differences between the downstream propagation in **equation** (4) and the upstream propagation in **equation** (6). First, demand shocks propagate upstream (from customers to suppliers). A shift in the demand of any sector implies a proportional change in the demand of intermediate inputs which that sector requires. Therefore, the relevant element of the $\hat{H}$ matrix is its $(i,\ j)$ position, which reflects the purchases of intermediate inputs that sector $i$ makes from sector $j$. That element shows how much the demand of sector $j$ will increase due to the rise in the demand of intermediate inputs that sector $i$ required to match the demand shock of the latter.

Second, the elements of the Leontief matrix $\hat{A}$ are normalized by the sales of the costumer sector (instead of production of the supplier industry as in $A$). The $(i,\ j)$ element of $\hat{A}$ is the sales of sector $j$ to sector $i$ normalized by total sales of sector $j$ ($\hat{a}_{ij} = \frac{p_i x_{ij}}{p_j y_j}$). Namely, it shows how important is sector $i$ as a client for any other industry $j$. The transmission of a demand shock goes from the directly exposed sector to its supplier industries by means of a change in the demand of intermediate inputs. Thus, contrary to the case with supply shocks, the relevant magnitude in a demand shock is the importance of the directly exposed sector as a customer of the rest of the economy.

Another relevant implication of **equation** (6) is that demand shocks only propagate upstream. An exogenous increase in the demand of sector $i$ affects quantities and thus the input demand from industry $i$'s suppliers, which represents a positive demand shocks to those industries' suppliers, and so on. However, demand shocks do not propagate downstream. This is a consequence of assuming constant returns to scale in the production function. Exogenous changes in the demand of sectors do not shift relative prices, so any change in the final demand of any sector does not change expenditure share for that same sector as an intermediate input.

## 2.4 On the aggregate impact of sector-specific shocks

While **equations** (4) and (6) capture the propagation of sector-specific shocks through the production chain, we are interested in the aggregate or economy-wide impact that we next discuss. Hulten's theorem (Hulten (1978)) states that in an efficient economy, and up to a first order approximation, the impact on aggregate GDP of a sector-specific productivity shocks is proportional to the sector's total sales. This result implies that, up to a first order approximation, the I-O structure of the economy is irrelevant for the aggregate change in GDP:

$$d\ln GDP_c = \sum_{j\in N_c} \lambda_j dz_j \tag{7}$$

where $\lambda_j = \frac{p_j y_j}{GDP_c}$ is the so-called Domar weight (Domar (1961))[11].

While Hulten's theorem provides a useful characterization of the aggregate impact of sector-specific shocks as exploited by Izquierdo et al. (2019), it is based on simplifying assumptions on two important dimensions that we next discuss.

### 2.4.1 The role of complementarities across inputs

A caveat of Hulten's theorem is the implicit assumption of unitary elasticity of substitution among inputs. Under a Cobb-Douglas production function, expenditure shares remain constant and therefore the Domar weights are invariant to shocks. However, this is not necessarily the case with a generalized CES production function as in Baqaee & Farhi (2019). In this setting, Domar weights are endogenous to industry-specific shocks to the extent that prices will react and, with non-unitary elasticity of substitution, customer industries and final consumers will adjust their expenditure shares.

Therefore, the Domar weights in **equation** (7) react endogenously to sector-specific shocks. In particular, the second order effect of a supply shock to sector $j$ will be equal to the change in the sales shares of the sector following the shock to any other sector $i$:

$$\frac{\mathrm{d}^2 \ln GDP}{\mathrm{d}\ln z_j \cdot \mathrm{d}\ln z_i} = \frac{\mathrm{d}\ln \lambda_j}{\mathrm{d}\ln z_i} \tag{8}$$

The change in sector $j$'s Domar weight is given by the substitution effect described in **equation 5**:

$$\frac{\mathrm{dln}\lambda_j}{\mathrm{d}\ln z_i} = \sum_{s=1}^{N} \frac{p_s y_s}{p_j y_j} (\theta_s - 1) \left[ \sum_{m=1}^{N} a_{sm} h_{mj} h_{mi} - \left( \sum_{m=1}^{N} a_{sm} h_{mi} \right) \left( \sum_{m=1}^{N} a_{sm} h_{mj} \right) \right] \tag{9}$$

[11] It is noteworthy that the elasticity between sector productivities and aggregate production is proportional to the sector's gross sales rather than to each sector's contribution to GDP. Therefore, an implication of the Hulten's theorem is that if all sectors experience a unitary shock ($dz_j = 1\ \forall j$), the aggregate impact may be larger than one. The reason is that the sum of Domar weights (also called input-output multiplier) is greater than or equal to the sum of value added of all industries.

How do the sales of a sector $j$ following a cost shock to industry $i$? It will depend on two factors: how much do both sectors share their customer base and how much does sector $j$ relies on sector $i$ as an input supplier.

Let's assume, for the sake of clarity, let's assume that material inputs show a high degree of complementarity ($\theta_j < 1$) among each other and sector $i$ experiences a negative productivity shock. Following the negative cost shock to good $i$, producer $s$ will increase its total expenditure on those sectors with rising costs (measured by the $i$-th column of the inverse Leontief matrix H). Therefore, there are two confronting mechanisms. On the one hand, industry $j$ will reduce its total sales because its customer base will shift part of the expenditure in favor of industry with higher costs. On the other hand, its sales will increase if industry $i$ is one of its main input suppliers so its costs also increase following the negative shock to the latter.

The overall effect depends on the respective columns of matrix H. This matrix measures both the direct and indirect impact between sectors. This implies that it is not necessary that both industries $i$ and $j$ to be direct suppliers of the rest of sectors. For instance, if sector $i$ is a major input supplier for industry $j$, the covariance of the respective columns of matrix H will be high, even in the case that industry $i$ does not sell to any other sector. The reason is that any price change in $i$ will pass through $j$ and will affect indirectly to sector $j$'s clients.

### 2.4.2 The role of correlated shocks across countries

Another important implication of **equation** (7) is that, to a first order approximation, productivity shocks to foreign producers have no effect on domestic GDP. The change in output of local producers following a productivity shock to a foreign supplier is offset by a change in the trade balance. Therefore, the local output accounting remains unchanged.

However, once second order approximations are considered as discussed in the previous subsection, productivity shocks to foreign suppliers might also affect local expenditure shares. In particular, if different sectors in a given country rely on its foreign counter-parts as input suppliers, the Domar weights of the local industries will react to the shocks. Thus, the effect of the productivity shock might be magnified in comparison to the case in which the shock affects only the local industry.

In **section 4**, we explore the particularly relevant case in which the same industrial sector is exposed to a contemporaneous shock in several countries, which brings together the non-linear effects of productivity shocks and the input-output relationships in open economies. This is particularly a relevant example in a context like the European Union in which a regulation change (which might be seen as a productivity shock) affects symmetrically to the same industry across different countries. In sectors in which domestic and foreign producers are highly interconnected through a customer-supplier relationship, the second order effect.

# 3 Data

In this section, we describe the main features of an Input-Output table as well as the main database used in the paper, the so-called World Input-Output Database (WIOD).[12] In an international I-O table, the structure of the world economy can be represented by the transaction flows across various country-sector pairs. To be more concrete, e can distinguish three quadrants in an standard I-O table as it is shown in **Table 1**. The heart of the I-O table is the intermediate consumption quadrant **Q1**. The entries in each row of this quadrant account for the quantities of output that a particular country-industry sells as intermediate inputs to other country-industries in the different columns.

An I-O table is generally closed by adding two other quadrants: (a) the final demand

**Table 1:** Stylized representation of a 2 country Input Output Table (WIOD)

| | | Purchasing industries | | | | | | | | | | Purchases by Final Demand categories | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| supply from industry | | Intermediates | | | | | | | | | | Final goods | | | | | |
| | | Country A | | | | | Country B | | | | | Country A | | | Country B | | |
| | | s1 | s2 | ... | ... | s56 | s1 | s2 | ... | ... | s56 | CONS | GFCF | INVEN | CONS | GFCF | INVEN |
| | s1 | | | | | | | | | | | | | | | | |
| | s2 | | | | | | | | | | | | | | | | |
| | ... | | | | | | | | | | | | | | | | |
| | s56 | | | | | | | | | | | | | | | | |
| Delivering industries | s1 | | | | | Q1 | | | | | | | | Q2 | | | |
| | s2 | | | | | | | | | | | | | | | | |
| | ... | | | | | | | | | | | | | | | | |
| | s56 | | | | | | | | | | | | | | | | |
| | WAGES | | | | | | | | | | | | | | | | |
| | OPERATING SURPLUS | | | | | | | | | | | | | | | | |
| Primary inputs | TAXES AND SUBSIDIES | | | | | Q3 | | | | | | | | | | | |
| | GROSS OUTPUT | | | | | | | | | | | | | | | | |
| | VALUE ADDED | | | | | | | | | | | | | | | | |

*Notes:* Own elaboration. Quadrant Q1 accounts for inter-sectoral linkages of intermediate sales and consumption by sectors $i$=1,2,...,56. Quadrant Q2 stands for final sales good by industry to final sectors. $s\_i$ stands for sector/industry $i$. Quadrant Q3 captures the primary inputs on employment (wages), gross operating surplus, taxes and subsidies, value added and gross output by each industry.

quadrant **Q2**, which represents the distribution of each sector final output across consumption (either by households or government), investment, and exports; and (b) the primary inputs quadrant **Q3** which captures employment (wages), the gross operating surplus, taxes and subsidies, value added and gross output for each sector. Note that in our example in **Table 1** the intermediate inputs from **Q1** includes the requirements

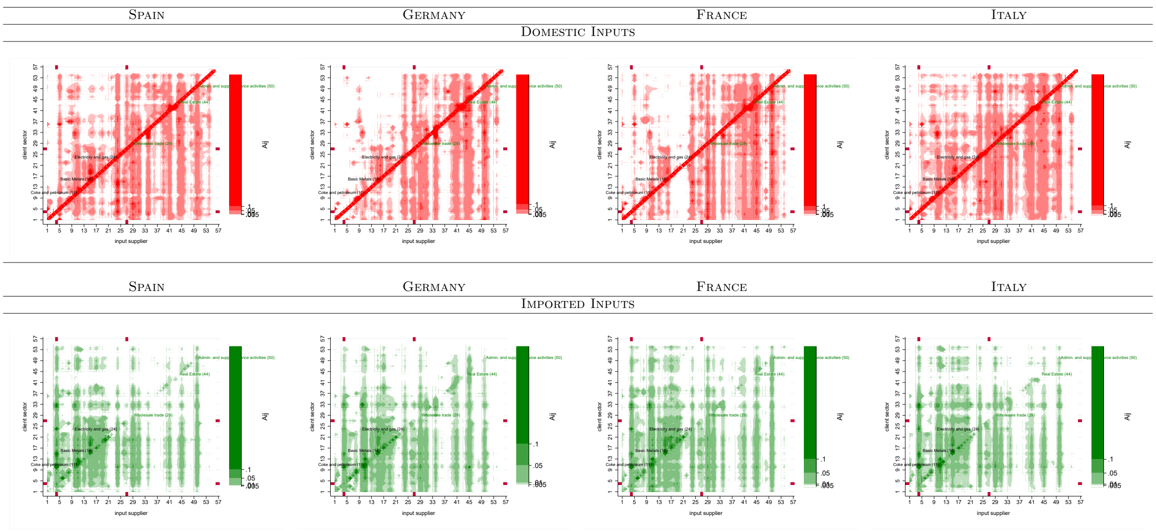
[12] The usage of the World Input-Output tables is becoming widely used in the literature as discussed for instance in Frohm & Gunnella (2017).

from each pair of country-industry so that we do not include in quadrant **Q3** the row measuring total inputs from abroad (imports) for each industry.

Turning to the data source, we use the World Input-Output Database (WIOD) with data for the year 2014. Since Timmer et al. (2016) provide a detailed description of this database, we simply comment its main characteristics here. The main advantage of using this data source is that it is fully homogenized across countries, which allows us to compute and compare country-specific I-O multipliers. In particular, WIOD is con-structed from a time-series of national supply and use tables (SUTs) for each country, taking as inputs national accounts data and benchmark supply and use tables (see Di-etzenbacher (1997) and Timmer et al. (2016) for more details). The dataset contains the I-O tables for 43 countries covering more than 85 per cent of world GDP over the period 2000-2014 (additionally it contains a Rest of the World observation). As regards the industry breakdown, it provides information of 56 industries classified according to ISIC rev.4 nomenclature. Data from WIOD provides us with a weighted adjacency ma-trix describing the network structure of the world economy. The network is composed by $2464^2$ nodes (the combinations between each of the 44x56 country-industry pairs) and the commercial flows between each of country-industry pairs are weighted directed edges. Note that 83.24% of the nodes are directly connected with non-zero intersectoral flows.

**Figure 1** plots in red the graphical representation of the total domestic requirement matrices (**H**) computed from national sections of WIOD data for Spain, Germany, France

**Figure 1:** Input-output requirement matrices in advanced economies in 2014




*Notes:* These graphs depict the total technical input requirements, both direct and indirect, by client industry $i$. Element $i, j$ represents the amount of value added embed by industry $i$ in goods from industry $j$ to produce a euro. It can be observed that (1) the main source is usually from the same as the producer sector, and (2) that manufacturing supplies are likely to be sourced from abroad. A contour plot method is used, showing only those shares greater than 1, 2, 5 and 10 percent.

Source: WIOD 2016 release.

and Italy and in green the total required imported inputs to produce one unit of output. A white node denotes that there is no significant connection between two sectors. While darker nodes point to a higher requirement from that sector to produce one unit of output. The darker colors in the diagonal of the domestic input matrices shows that firms in any sector tends to primarily rely on other firms of their own sector as an input supplier. And on the other hand, when looking at imported inputs, the panels in green, this effect prevails only among manufacturing industries. By comparing these matrices it can be observed the that the input-output network is more intense in some manufacturing sectors and restricted to some service industries (such as Wholesale trade (G45), Real estate (L68) and Administrative support services (N)).[13]

# 4 Results

In this section, we illustrate the importance of complementarities across inputs and correlated shocks across countries in the propagation of worldwide sector-specific shocks. In particular, we calibrate the theoretical model in **section 2** using the World Input-Output Database (WIOD) described in **section 3**. Moreover, as we depart from the unitary elasticity of substitution, we need to also calibrate values for the elasticity of substitution across inputs ($\theta_i$) and the elasticity of substitution across industries in consumption ($\theta_0$). We assume that the elasticity of substitution across inputs $\theta_i = 0.2$ and the elasticity in consumption to be $\theta_0 = 0.9$. These values are consistent with estimates in the literature (see Atalay (2017), Boehm et al. (2015), Oberfield & Raval (2014), and Herrendorf et al. (2013)). The parameter $\theta_i$ indicates a higher degree of complementarity among material inputs than the one observed at the consumer level.

Armed with our calibrated model-economy, we consider a 20% drop in TFP in each sector and compute the economy-wide impact under two scenarios: the linear case ($\theta_i = 1$) with country-specific shocks, and the non-linear case ($\theta_i \neq 1$) with worldwide shocks common across countries. The resulting aggregate effects are reported in **table 2** for Spain, Germany, France and Italy.

We observe a substantial amplification effect when shocks are common to the different countries in the case of manufacturing industries (ISIC code C). This implies that the economy-wide impact of a sector-specific shock is substantially amplified when the same sector in other countries is also hit in the presence of complementarities. For example, the

[13]Moreover, when computing the *upstream* and *downstream* multipliers, which is the sum of the columns or the rows as it is done Izquierdo et al. (2019) it can be observed that there are differences between countries and sectors.

country-sector pair that shows the highest amplification is C10-12 *Manufacturing of Food and Beverages* in Spain. If the 20% fall in TFP affects only the Spanish industry of manufacturing food and beverages, the aggregate impact on Spanish GDP is -2.7%. However, this impact is amplified to -3.6% when the TFP shock hits the other countries as well in the presence of complementarities, resulting in an amplification of 0.85 pp in Spain (31% larger). Interestingly enough, this amplicifation is substantial but relatively lower in the case of Germany (23%), France (19%), and Italy (25%). On the other hand, significant amplification effects are also observed in sector C29 *Manufacturing of motor vehicles*, specially in Germany and Spain. These results are in line with the high partic-ipation in Global Value Chains and sector interdependences of manufacturing industries that are upstream in the production chain.

In contrast, turning to non-manufacturing sectors (ISIC code D to U), the aggregate impact is very similar under both scenarios in all countries according to the figures in **table 2**. This result implies that the economy-wide effect of shocks to non-manufacturing industries is not amplified when there are complementarities in production and correlated shocks across countries. Note for example that sectors such as Real Estate (L68) present a high Domar weight, and therefore have a substantial aggregate impact, but the amplification effect is negligible.

**Table 2:** Aggregate impact of a sector specific 20% negative TFP shock

| ISIC code | Spain | | | Germany | | | France | | | Italy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Linear | Common | Ampl | Linear | Common | Ampl | Linear | Common | Ampl | Linear | Common | Ampl |
| A01 | -0.848 | -1.008 | -0.16 | -0.349 | -0.413 | -0.06 | -0.795 | -0.982 | -0.19 | -0.713 | -0.858 | -0.14 |
| A02 | -0.020 | -0.023 | -0.00 | -0.036 | -0.044 | -0.01 | -0.051 | -0.064 | -0.01 | -0.020 | -0.023 | -0.00 |
| A03 | -0.056 | -0.065 | -0.01 | -0.003 | -0.003 | -0.00 | -0.023 | -0.027 | -0.00 | -0.022 | -0.025 | -0.00 |
| B | -0.124 | -0.144 | -0.02 | -0.081 | -0.094 | -0.01 | -0.055 | -0.063 | -0.01 | -0.135 | -0.157 | -0.02 |
| C10-C12 | -2.726 | -3.581 | -0.85 | -1.358 | -1.650 | -0.29 | -1.556 | -1.901 | -0.34 | -1.690 | -2.129 | -0.44 |
| C13-C15 | -0.407 | -0.491 | -0.08 | -0.165 | -0.198 | -0.03 | -0.163 | -0.196 | -0.03 | -1.064 | -1.382 | -0.32 |
| C16 | -0.117 | -0.143 | -0.03 | -0.177 | -0.220 | -0.04 | -0.104 | -0.127 | -0.02 | -0.191 | -0.241 | -0.05 |
| C17 | -0.249 | -0.311 | -0.06 | -0.282 | -0.357 | -0.08 | -0.164 | -0.200 | -0.04 | -0.281 | -0.357 | -0.08 |
| C18 | -0.163 | -0.196 | -0.03 | -0.151 | -0.180 | -0.03 | -0.096 | -0.112 | -0.02 | -0.152 | -0.180 | -0.03 |
| C19 | -0.927 | -1.110 | -0.18 | -0.582 | -0.693 | -0.11 | -0.485 | -0.573 | -0.09 | -0.702 | -0.842 | -0.14 |
| C20 | -0.995 | -1.251 | -0.26 | -1.014 | -1.254 | -0.24 | -0.676 | -0.838 | -0.16 | -0.670 | -0.850 | -0.18 |
| C21 | -0.291 | -0.346 | -0.06 | -0.337 | -0.408 | -0.07 | -0.249 | -0.296 | -0.05 | -0.324 | -0.397 | -0.07 |
| C22 | -0.357 | -0.433 | -0.08 | -0.555 | -0.661 | -0.11 | -0.305 | -0.362 | -0.06 | -0.528 | -0.636 | -0.11 |
| C23 | -0.315 | -0.382 | -0.07 | -0.330 | -0.395 | -0.06 | -0.240 | -0.288 | -0.05 | -0.406 | -0.491 | -0.08 |
| C24 | -0.815 | -1.029 | -0.21 | -0.739 | -0.947 | -0.21 | -0.325 | -0.410 | -0.08 | -0.732 | -0.937 | -0.21 |
| C25 | -0.559 | -0.665 | -0.11 | -0.926 | -1.132 | -0.21 | -0.491 | -0.596 | -0.10 | -1.053 | -1.295 | -0.24 |
| C26 | -0.140 | -0.165 | -0.03 | -0.537 | -0.637 | -0.10 | -0.227 | -0.269 | -0.04 | -0.288 | -0.345 | -0.06 |
| C27 | -0.316 | -0.377 | -0.06 | -0.759 | -0.913 | -0.15 | -0.203 | -0.241 | -0.04 | -0.469 | -0.567 | -0.10 |
| C28 | -0.481 | -0.567 | -0.09 | -1.746 | -2.104 | -0.36 | -0.375 | -0.445 | -0.07 | -1.459 | -1.777 | -0.32 |
| C29 | -1.001 | -1.246 | -0.25 | -2.461 | -3.067 | -0.61 | -0.531 | -0.652 | -0.12 | -0.630 | -0.762 | -0.13 |
| C30 | -0.319 | -0.379 | -0.06 | -0.295 | -0.358 | -0.06 | -0.589 | -0.722 | -0.13 | -0.292 | -0.347 | -0.05 |
| C31_C32 | -0.244 | -0.286 | -0.04 | -0.370 | -0.433 | -0.06 | -0.164 | -0.192 | -0.03 | -0.492 | -0.594 | -0.10 |
| C33 | -0.209 | -0.247 | -0.04 | -0.286 | -0.333 | -0.05 | -0.515 | -0.617 | -0.10 | -0.251 | -0.292 | -0.04 |
| D35 | -1.848 | -1.848 | 0.00 | -0.945 | -0.945 | 0.00 | -1.078 | -1.078 | 0.00 | -1.120 | -1.120 | 0.00 |
| E36 | -0.190 | -0.192 | -0.00 | -0.067 | -0.068 | -0.00 | -0.097 | -0.097 | -0.00 | -0.118 | -0.121 | -0.00 |
| E37-E39 | -0.328 | -0.329 | -0.00 | -0.353 | -0.354 | -0.00 | -0.282 | -0.283 | -0.00 | -0.516 | -0.520 | -0.00 |
| F | -2.505 | -2.506 | -0.00 | -2.025 | -2.028 | -0.00 | -2.760 | -2.762 | -0.00 | -2.715 | -2.717 | -0.00 |
| G45 | -0.553 | -0.548 | 0.01 | -0.437 | -0.435 | 0.00 | -0.457 | -0.449 | 0.01 | -0.456 | -0.453 | 0.00 |
| G46 | -1.939 | -1.939 | -0.00 | -1.508 | -1.509 | -0.00 | -2.070 | -2.069 | 0.00 | -2.155 | -2.156 | -0.00 |
| G47 | -1.547 | -1.534 | 0.01 | -1.180 | -1.175 | 0.00 | -1.369 | -1.364 | 0.01 | -1.579 | -1.569 | 0.01 |
| H49 | -0.996 | -0.995 | 0.00 | -0.718 | -0.719 | -0.00 | -0.820 | -0.822 | -0.00 | -1.207 | -1.205 | 0.00 |
| H50 | -0.065 | -0.065 | -0.00 | -0.192 | -0.195 | -0.00 | -0.144 | -0.144 | -0.00 | -0.166 | -0.169 | -0.00 |
| H51 | -0.205 | -0.206 | -0.00 | -0.189 | -0.190 | -0.00 | -0.196 | -0.196 | -0.00 | -0.152 | -0.152 | -0.00 |
| H52 | -0.832 | -0.840 | -0.01 | -0.896 | -0.903 | -0.01 | -0.584 | -0.586 | -0.00 | -0.850 | -0.855 | -0.01 |
| H53 | -0.093 | -0.093 | -0.00 | -0.217 | -0.228 | -0.01 | -0.124 | -0.124 | -0.00 | -0.092 | -0.093 | -0.00 |
| I | -2.270 | -2.270 | 0.00 | -0.616 | -0.616 | -0.00 | -0.962 | -0.962 | 0.00 | -1.352 | -1.352 | -0.00 |
| J58 | -0.152 | -0.151 | 0.00 | -0.239 | -0.239 | 0.00 | -0.248 | -0.247 | 0.00 | -0.123 | -0.123 | 0.00 |
| J59_J60 | -0.235 | -0.235 | -0.00 | -0.235 | -0.235 | -0.00 | -0.263 | -0.266 | -0.00 | -0.196 | -0.196 | -0.00 |
| J61 | -0.692 | -0.693 | -0.00 | -0.463 | -0.463 | -0.00 | -0.589 | -0.591 | -0.00 | -0.516 | -0.522 | -0.01 |
| J62_J63 | -0.566 | -0.568 | -0.00 | -0.821 | -0.826 | -0.00 | -0.731 | -0.735 | -0.00 | -0.648 | -0.652 | -0.00 |
| K64 | -0.832 | -0.833 | -0.00 | -1.070 | -1.077 | -0.01 | -1.164 | -1.170 | -0.01 | -1.202 | -1.208 | -0.01 |
| K65 | -0.379 | -0.389 | -0.01 | -0.548 | -0.556 | -0.01 | -0.584 | -0.595 | -0.01 | -0.310 | -0.318 | -0.01 |
| K66 | -0.163 | -0.177 | -0.01 | -0.242 | -0.278 | -0.04 | -0.376 | -0.415 | -0.04 | -0.396 | -0.408 | -0.01 |
| L68 | -2.634 | -2.633 | 0.00 | -2.802 | -2.800 | 0.00 | -3.043 | -3.044 | -0.00 | -3.063 | -3.061 | 0.00 |
| M69_M70 | -0.577 | -0.577 | 0.00 | -0.973 | -0.987 | -0.01 | -1.527 | -1.525 | 0.00 | -0.944 | -0.936 | 0.01 |
| M71 | -0.450 | -0.451 | -0.00 | -0.470 | -0.482 | -0.01 | -0.616 | -0.623 | -0.01 | -0.400 | -0.411 | -0.01 |
| M72 | -0.130 | -0.130 | -0.00 | -0.229 | -0.229 | -0.00 | -0.603 | -0.603 | 0.00 | -0.180 | -0.181 | -0.00 |
| M73 | -0.183 | -0.183 | 0.00 | -0.175 | -0.175 | -0.00 | -0.188 | -0.187 | 0.00 | -0.201 | -0.202 | -0.00 |
| M74_M75 | -0.115 | -0.116 | -0.00 | -0.170 | -0.170 | -0.00 | -0.127 | -0.128 | -0.00 | -0.290 | -0.291 | -0.00 |
| N | -1.030 | -1.031 | -0.00 | -1.538 | -1.540 | -0.00 | -1.791 | -1.795 | -0.00 | -1.240 | -1.245 | -0.01 |
| O84 | -1.714 | -1.714 | -0.00 | -1.803 | -1.802 | 0.00 | -2.163 | -2.161 | 0.00 | -1.721 | -1.714 | 0.01 |
| P85 | -1.328 | -1.312 | 0.02 | -1.137 | -1.123 | 0.01 | -1.273 | -1.254 | 0.02 | -0.977 | -0.965 | 0.01 |
| Q | -1.896 | -1.878 | 0.02 | -2.110 | -2.090 | 0.02 | -2.341 | -2.322 | 0.02 | -1.981 | -1.967 | 0.01 |
| R_S | -1.066 | -1.054 | 0.01 | -1.078 | -1.062 | 0.02 | -0.915 | -0.900 | 0.01 | -1.106 | -1.094 | 0.01 |
| T | -0.186 | -0.184 | 0.00 | -0.055 | -0.054 | 0.00 | -0.035 | -0.035 | 0.00 | -0.256 | -0.254 | 0.00 |
| U | 0.000 | 0.000 | 0.00 | 0.000 | 0.000 | 0.00 | 0.000 | 0.000 | 0.00 | 0.000 | 0.000 | 0.00 |

*Notes:* A negative tfp shock of 20% in each sector leads to an aggregate decline in GDP in pp as reported in the column "Linear", when taking into account non-linearities and a common shock aggregate impact is repoted in colum "Common". In column "Amplification" we report the amplification effect. Note that this amplification effect is higher in the manufacturing sector and negligible in the service sector.

In order to shed further light on these findings, we next focus on two particular sectors and explore in more detail the amplification effects of different shocks.

### Green-induced regulations in manufacturing

The increasing awareness on the need to curb greenhouse emissions, in order to tackle climate change, calls for actions at the EU level that may impact the manufacturing industry in EU countries simultaneously. For instance, the EU legislation on pollutant emissions in the context of the Worldwide Harmonised Light Vehicle Test Procedure (WLTP) that came into force in September 2018 is supposed to provide more realistic emission and fuel consumption figures thus inducing stricter limits for European car manufacturers. In particular, under the new EU regulation (EU) 2017/1151, the application of a new protocol for the measurement of automobile pollutant emissions is mandatory and all new vehicle registrations must comply with a more stringent protocol for the measurement of fuel consumption and emissions. Although this regulatory change has different effects on the car industry, the most immediate impact is related to the need for car manufacturers to adapt their production systems to ensure that vehicles comply with the new legal requirements and thus it can be interpreted as a negative technology shock for this sector. In this context, this WLTP shock can be interpreted as a negative supply shock to the entire European car manufacturing industry.

Since it is far from straightforward to calibrate the impact of this regulation on sector-specific TFP, we consider a wide range of TFP shocks (from -40% to +30%) in **Figure 2**. In particular, this figure shows graphically the aggregate impact of TFP shocks to the the C29-*Manufacturing of motor vehicles* in Spain, Germany, France and Italy. The three red lines represent the calibrated effect on each country's GDP of a supply shock to sector C29 under three assumptions. First, the "Domar weight" case that considers only linear effects (i.e. a unitary elasticity of substitution). In this case, the aggregate effect on each country GDP is the multiplication of the Domar weight multiplied by the magnitude of the shock. Second, the "Non-linear - isolated shock" case in which the TFP shock hits the sector within each country but into account complementarities (i.e. the fact that sales share responds to price changes). Third, the "Non-linear - common shock" case in which the *Manufacturing of motor vehicles* in every country of the EU experiences the same TFP shock calibrated in the x-axis.

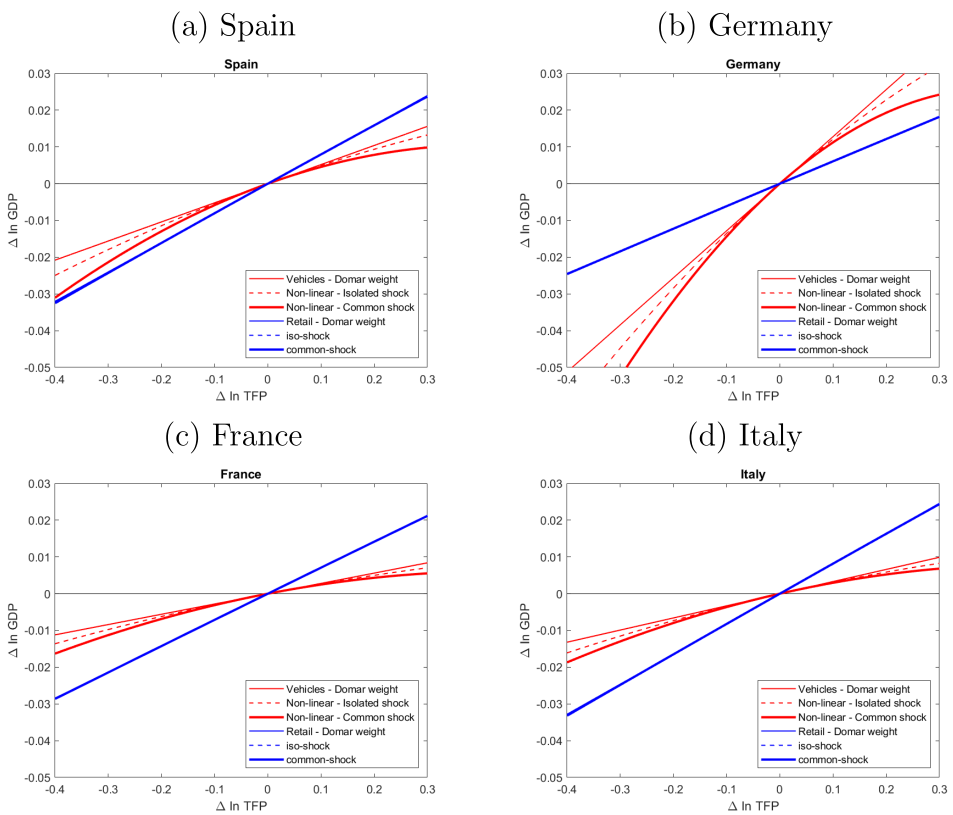
Looking at the different lines in **Figure 2**, one main conclusion emerges. Complementarities and correlated shocks substantially amplify negative shocks but mitigate positive shocks. When a negative shock hits a particular industry in a given country and its price rise, the corresponding fall in demand is amplified if the same industry in other countries is also hit by the negative shock. Intuitively, the resulting price hike for Spanish cars is larger when the TFP of the German automotive industry decreases as well. This is so because the car industry in both countries requires the same inputs that are comple-ments to other inputs and thus the overall input costs increase by more when two different customers are simultaneously hit by a negative TFP shock. In the case of positive TFP socks, the corresponding reduction in prices of the same sector in other countries leads to a mitigation of the aggregate impact. This is the case because the benefits of a positive TFP shock (price reduction) for the Spanish automotive industry is milder if the Ger-man car industry experiences the same positive TFP shock and the resulting fall in prices.

## COVID-induced digitalization in services

An additional application of this framework can be the impact of digitization in one particular sector which leads to a positive TFP shock. In particular, we analyze the impact of a shock in the retail trade sector, G47-*Retail trade*, a sector in which during the last years registered increased digitization, by augmenting the share of sales through on-line platforms. This was led by higher efficiency gains in distribution handling and an increase in online price competition which helped to reduce costs.[14] It is expected that these trends such as the increase in on-line shopping, were boosted by the COVID-19 shock.

**Figure 2** also shows the calibrated impacts of TFP shocks to the retail sector on each country's aggregate activity (blue lines), analogous to the case of the manufacturing vehicles industry (red lines). In the case of retail, the three blue lines overlap, which means

**Figure 2:** TFP shock to Manufacturing of motor vehicles and Retail trade




*Notes:* These graphs plot the aggregate impact on each country GDP following a sector specific shock in sector C29-*Manufacturing of motor vehicles* in red and sector G47-*Retail trade* in blue, under three scenarios: the linear impact based on Domar weights with neither complementaries nor correlated shocks; the impact when considering non-linearities and country-specific (isolated shock) shocks to each sector; the case where there are both complementarities and the shock hits the same sector in different countries (common shock).

[14]In Lacuesta et al. (2020) estimate that Spanish firms that increased their share of on-line shares by 10pp led to a decline in markups by 0.4pp while keeping other variables, such as profits, unchanged.

that the impact on aggregate activity is virtually the same in all the scenarios. In particular, the aggregate impact is well-approximated by the Domar weight multiplied by the size of the shock, even in the presence of non-linearities and correlated shocks across countries. The scarcity of interconnections as supplier to other sectors given its downstreamness in the supply chain (retail is close to the final consumer) and its low degree of globalization leaves little room for non-linearities and for the amplification (mitigation) of negative (positive) supply shocks.

# 5 Conclusions

Several policy-relevant scenarios have an asymmetric impact across sectors. Thus, to know their aggregate impact, it is necessary to know their propagation to the rest of the economy. Moreover, several cases like the implementation of environmental regulation or the pandemic-induced digitalization of services, happen simultaneously in several national economies. For this reason, the propagation of those sector-specific shocks needs to be assessed under the assumption of taking place simultaneously across different countries. We show that the latter point has special relevance for industries, such as manufacturing, with highly integrated global value chains.

This paper sheds light on this issue by considering a model of production networks with complementarities across inputs and calibrated to the world input-output database (WIOD). According to our results, in the presence of input complementarities, the aggregate impact of negative supply shocks to manufacturing industries is substantially amplified when the shock is common to all countries. The results stem from the high degree of international integration of these industries. Given the input complementarities, industries cannot fully substitute those providers so they increase their expenditure in industries facing the negative shock. In the case of manufacturing, in the case of a common shock across different countries, the effect of the negative shock to the own sector compounds with the rising costs of its main suppliers. On the opposite side, we show that the effect of a positive shock to any given manufacturing industry is attenuated when it is simultaneous to several countries.

Finally, this amplification/mitigation effect is much more muted in the case of non-manufacturing industries. As long as services typically do not rely on their peers from other countries as input suppliers, the consequences of a common shock do not compound.

Overall, this finding casts doubt on the appropriateness of economy-wide impacts estimated based on country-specific shocks in a given industry if these shocks are also present in other countries (e.g. green-induced regulations).

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# A Proofs

## A.1 Change in prices

From the first order conditions derived from the maximizing profits of firm $i$ and plugging into equation 1 we obtain the following expression in matrix notation:

$$\begin{aligned} \mathrm{d}\ln p &= -\mathrm{d}Z + A\mathrm{d}\ln p \\ \mathrm{d}\ln p &= -\left(I-A\right)^{-1}\mathrm{d}Z \\ &= -H\mathrm{d}Z \end{aligned}$$

Where $\mathrm{d}\ln p$ is vector of changes in (relative) prices, $A$ is the economy´s input-output matrix and $dZ$ is the vector of productivity shocks. A positive productivity shock leads to a decline in prices.

## A.2 Change in expenditure shares and Domar weights

Following a productivity shock to any sector $k$, the share of expenditure that sector $j$ makes on the product of sector $i$ depends on the importance of sector $k$ for sector $i$ (direct change in price) as well as on the effect of sector $k$ on the rest of suppliers of sector $j$. In other words, it weights the change in the price of good $i$ minus the weighted change in price of the rest of goods.

$$\frac{\mathrm{d}\ln a_{ji}}{\mathrm{d}\ln z_k} = (\theta_j - 1)\left[h_{ik} - \sum_{g=1}^{N+1} h_{gk} a_{jg}\right]$$

Following a productivity shock to any sector $k$, the change in sector $i$'s Domar weight changes according to two elements. First, the change in expenditure in good $i$ of every other sector, weighted by these sectors' sales. Second, the change in sales of every other sector weighted by the share that those sectors expend on good $i$. Note that sector sales include sales to final consumers; therefore, the sum includes the $N$ plus the final consumer.

$$\lambda_i = \frac{p_i y_i}{GDP} = \sum_{j=1}^{N+1} \frac{p_i x_{ji}}{p_j y_j} \cdot \frac{p_j y_j}{GDP} = \sum_{j=1}^{N+1} a_{ji}\lambda_j$$

The change of sector $i$'s Domar weight (sector $i$ sales over GDP) is the change in the share of expenditure that every other sector makes on the sector weighted by the sales of each sector.

$$
\begin{aligned}
\frac{\mathrm{d}\lambda_i}{\mathrm{d}\ln z_k} &= \sum_{j=1}^{N+1} a_{ji}\lambda_j \frac{\mathrm{d}\ln a_{ji}}{\mathrm{d}\ln z_k} + \sum_{j=1}^{N+1} a_{ji}\frac{\mathrm{d}\lambda_j}{\mathrm{d}\ln z_k} \\
&= \sum_{j=1}^{N+1} (\theta_j - 1)\,\lambda_j a_{ji}\left[h_{ik} - \sum_{g=1}^{N+1} h_{gk}a_{ig}\right] + \sum_{j=1}^{N+1} a_{ji}\frac{\mathrm{d}\lambda_j}{\mathrm{d}\ln z_k}
\end{aligned}
$$

Noting that $H = (I - A)^{-1}$

$$
\begin{aligned}
\frac{\mathrm{d}\lambda_i}{\mathrm{d}\ln z_k} &= \sum_{m=1}^{N+1} h_{mi} \sum_{j=1}^{N+1} (\theta_j - 1)\,\lambda_j a_{jm}\left[h_{mk} - \sum_{g=1}^{N+1} h_{gk}a_{mg}\right] \\
&= \sum_{j=1}^{N+1} (\theta_j - 1)\,\lambda_j \left[\sum_{m=1}^{N+1} a_{jm}h_{mi}h_{mk} - \left(\sum_{m=1}^{N+1} a_{jm}h_{mi}\right)\left(\sum_{g=1}^{N+1} a_{mg}h_{gk}\right)\right] \\
&= \sum_{j=1}^{N+1} (\theta_j - 1)\,\lambda_j \left[A_{(j,\cdot)}H_{(\cdot,i)}H_{(\cdot,k)} - \left(A_{(j,\cdot)}H_{(\cdot,i)}\right)\left(A_{(m,\cdot)}H_{(\cdot,k)}\right)\right]
\end{aligned}
$$

Thus, the elasticity of sector $i$'s Domar weight with respect to a productivity shock on any given sector $z$ is:

$$
\frac{\mathrm{d}\ln\lambda_i}{\mathrm{d}\ln z_k} = \sum_{j=1}^{N+1} (\theta_j - 1)\,\frac{\lambda_j}{\lambda_i}\left[\sum_{m=1}^{N+1} a_{jm}h_{mi}h_{mk} - \left(\sum_{m=1}^{N+1} a_{jm}h_{mi}\right)\left(\sum_{g=1}^{N+1} a_{mg}h_{gk}\right)\right]
$$

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