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Sector-specific shock propagation heterogeneity in international production networks: case of EU regions

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ORIGINAL ARTICLE

Abstract. This article examines sector-specific heterogeneity in shock propagation across international production networks. The study investigates whether the impact of sectoral shocks on regional output depends on two structural characteristics of European regions: their geographical and economic proximity to other regions and the degree of industrial diversification. The empirical analysis is based on the EUREGIO interregional input-output database covering 252 NUTS2 regions of the EU-2006 and twelve aggregated economic sectors for 2010. Shock propagation is modelled using the hypothetical extraction method, which simulates the temporary removal of an industry from international intersectoral production linkages. Geographical and economic proximity is measured by the geographically weighted location quotient, while industrial diversification is assessed using the Herfindahl-Hirschman Index. The results reveal substantial sectoral heterogeneity in shock propagation. Strong positive relationships between regional vulnerability to shocks and both explanatory variables are identified for knowledge-intensive service sectors, particularly real estate and business services and financial intermediation. A weaker positive relationship is observed in electrical, optical and transport equipment, whereas mining and energy supply demonstrate an inverse relationship. No systematic relationship is found for labour-intensive sectors such as agriculture, textiles, and food production. The findings suggest that knowledge-intensive services play a systemic role in transmitting shocks across European production networks, while greater industrial diversification enhances regional resilience by mitigating the economic consequences of sector-specific disruptions. These results contribute to the understanding of regional competitiveness, resilience and the structural determinants of shock propagation in international production networks.

Keywords: European production networks; shock propagation; geographic and economic proximity; sector heterogeneity; industrial diversification

JEL codes: C53, D57, F15, F23, O52

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Introduction

The modern world economy is increasingly more exposed to shocks originating from various sources (political, economic, ecological, technological, etc.). Importantly, shocks have a mutually reinforcing cumulative impact on the economy on different levels, including global, national, and regional. Among the main amplifiers of heterogeneous shocks is the network structure of the global production, which implies a close interconnectedness and interdependence of productive units on the inter-country and inter-industry planes. Considering a growing policy demand for resilience strategies of the national economies, the study of the network patterns of shock propagation at the regional level becomes important.

One of the most popular theoretical frameworks to study the dynamics of international production networks is the 'Global Production Networks' (hereinafter – GPN) paradigm. Under this framework international production is viewed as a complex process on the network cooperation between suppliers, producers, and other intermediaries on the matter of value addition to create sophisticated finished goods. Global production networks span through three main dimensions, namely organizational, network (or topological), and geographical. Organizational space stands for the production technologies as sequential chains of value addition to intermediary goods and their respective transfer to other counterparts. Network space depicts topologies of interfirm relations under production of complex goods and reflects, primarily, the number of a node's neighbors, its proximity in a production network, as well as the relational features of production network architecture. Geographic space, in its turn, traces the spatial positioning of firms and other intermediaries, thus highlighting the factor of partners' remoteness and specifics of logistical coordination of international production. Therefore, a simultaneous account of all the three spaces allows the GPN paradigm to act as a powerful tool for studying the role of firms' dynamics for the regional economic activities.

The network nature of international production implies a great degree of interdependence between firms and intermediaries originating from various countries and regions across the globe. Therefore, the behavior of individual firms may non-linearly impact other firms that do not directly collaborate with these actors. In other words, the evidence suggests divergent "network effects" as unintentional adverse effects experienced by network actors, which become visible through non-systematic shifts of the key indicators of firms' performance. At the same time, the 'shocks' propagation is subject to the organizational, network, and geographic properties of GPNs. Hence, shock propagation patterns may be conceived in terms of buyers and sellers of a specific firm's products (here – upstream and downstream flows), as well as its direct and indirect partners and their impact on firms operating in the same region or in other locations.

In Europe, international production networks have become particularly complex, compared to other countries and world regions. An increasing number of firms integrate into electronics, transport manufacturing, chemical production, as well as military. These sectors have very dense value chains, and a large portion of value creation is provided by knowledge-intensive business services. Hence, the structure of the European economy acquires the attributes of the system of strongly interconnected industries and regions. Owing to the recent developments in statistics of international production, the study of network configurations of international production at the regional level in Europe becomes feasible. A successful example production statistics compilation for regional economies is the "PBL EUREGIO" database that contains interregional input-output tables for different sectors across EU regions. The tables comprise both WIOD data and regional economic accounts. Additionally, they cover international trade estimations obtained by PBL Netherlands Environmental Agency that are complemented by regional output and economic costs data collected via survey over a specified number of countries. In addition, the quantitative tools allowing for a proper estimation of interregional geographical distances became publicly available. The "EUDISTANCE" project offers an estimable algorithm for measuring of distances between the centroids of European regions and creating of a complete matrix of distances for both NUTS2 and NUTS3 regions. In sum, there is a visible trend towards a formation of empirical toolkit for the regional level research into international production networks.

Given the level of production network sophistication, as well as the presence of relevant quantitative tools and databases, Europe provides a suitable empirical setting to study specifics of the shock propagation in international production networks. The present study aims at the identification of sector-specific features of shock propagation in the European production networks. The role of regional proximity and industrial diversification as factors of shock propagation is examined.

Literature review

The existing research into shock propagation in international and regional production is primarily centred around the network properties of production systems (technological and value connections between suppliers, assemblers, and other intermediaries), inter-industry shock propagation mechanisms, as well as vertical specialization in global value chains.

The above-mentioned GPN theoretical paradigm pays particular attention to the problem of production networks evolution and regional economic development [8; 20]. The researchers note that 'territoriality' in traditional global value chains research is studied at an overly aggregated level with countries being subdivided onto 'core economies' and 'peripheral economies'. GPN concept, in its turn, allows for identification of means whereby various network actors anchor into particular locations. The GPN concept proponents suggest for the production network to be territorially conceived as 'a spatial ensemble of different local and territorially centered value activities' [8]. An ongoing series of discussions on the international production networks' potential to transmit shocks originating from individual firms is present in the modern literature. It is argued that, apart from production network structure and lead firms' actions, external forces also shape shock propagation mechanisms. They include industrial specifics (i.e., technological profile, cost structure and firm competitiveness, industry standards, etc.) and regional properties (i.e., resource endowment, quality of infrastructure, labor market structure, regulatory profile, presence of other firms, etc.). It is stressed, though, that any given GPN research and, in particular, the one covering shock propagation is currently carried out on industry-level data. In other words, the researchers face the requirement to 'scale up' the level of analysis due to operational limitations for assessment of competitive dynamics' explanatory variables (cost-capability ratio, market structure, financial discipline, and external risks).

A significant breakthrough in research into shock propagation in international production networks was the formal modelling of international production networks based on the production function incorporating consumption of intermediates [2]. The main research directions covered studies of shock propagation patterns through the lens of network topologies [7], as well as investigation of the origins of supply and demand shocks and their upstream and downstream propagation channels [1]. The Hulten theorem has gained scholarly attention with respect to modelling the impact of shocks on the economy's output [12]. It posits that the changes in aggregate economy's output in response to a sector-specific shock are proportional to the share of this sector in the aggregate output (or to the so called 'Domar weight'). Several papers highlight the tendency of clustering around the most productive firms while studying shock propagation in GPNs [16]. Modelling of the impact of non-anthropogenic shocks on international production networks has also become a popular strand of the GPN studies. For instance, in [5] the authors study the shocks associated with natural disasters from the point of production networks' potential to amplify or mitigate them. The empirical modelling in the paper relied on the interfirm transactions between large US firms. As the study revealed, the natural disaster shocks had a more ruinous effect for the firms specializing in differentiated goods with higher R&D expenditures or otherwise important in the networks due to the difficulty of their substitution.

Due to data availability restrictions the qualitative assessment at the level of separate economies and their industries remains most widely used. Interregional input-output tables have served in the recent years as an empirical foundation for studying interindustry relations between countries and macroregions. The flagship work enhancing research into international production network studies from the point of inter-industry cooperation and value addition was the paper of Hummels et al. [13]. The authors' theoretical model of vertical specialization considers production as a two-stage process, where the first stage is executed solely by labor force, while the second one is performed by labor with the use of the first stage's output. Thus, production technologies are specified on the basis of the country (be that the country of origin or the other country) hosting the first and the second production stages. The work of Timmer et al. [19] has greatly popularized the input-output analysis of international production networks. The automotive manufacturing served as an example of a sector showing an increase in international production fragmentation seen in the ratio of value-added produced in the domestic economy, its macroregional partners, and other countries. In the paper of Los et al. [14] the research of Timmer et al. was further advanced by adding the emphasis to the dynamics of regional and global value-added components in international production. It has been revealed that there was a sustained growth in the ratio of value-added produced outside of the macroregion to intra-regional value-added for 34 largest economies from the EU, East Asia and North America over the period of 1995-2011. Recently input-output analysis of international production networks has shifted to the problem of risks to national economic performance associated with reliance on foreign partners. Baldwin and Freeman [4] identify two groups of risks – impacting production networks themselves (i.e., exogenous supply and demand shocks, natural disasters, changes in trade policy, entry of new competitors, etc.) and engendered by production networks (i.e., externalities of links' rupture, shock propagation on micro- and macrolevel, etc.). As the authors conclude, a trade-off between diversification of suppliers and reliance on the more quality intermediates is necessary to properly mitigate these risks. It is also articulated in the paper that such diversification hinders post-crisis recovering of production systems while maintaining relations with established partners assists a rapid recovery.

Heterogeneous patterns of shock propagation in specific sectors of international production networks are dissected in the literature. Bahal and Lenzo [3] proposed the 'removal centrality' parameter to measure the sector's potential to transmit and amplify exogenous shocks. The metric is calculated as the difference between the first-order changes in real GDP in the actual economy and in the counterfactual economy where the linkages between the focal industry and the other sectors are severed so that it becomes unable to transmit shocks. As the study revealed, the Domar weight measure substantially underestimates the systemic importance of some economic sectors due to its inability to account for inter-industry network linkages. The systemic importance of industries in the economy has also been considered in terms of the network centrality of a sector. In an earlier paper of Blöchl et al. [6] the authors relied on two measures to capture the sector's centrality, namely the random walk centrality, which is based on the idea of the expected number of steps required to reach another node for the first time, and the counting betweenness, reflecting the frequency of a given node being visited on first-passage walks. According to the study, the random walk centrality has attributed the greatest systemic importance to wholesale and retail trade sectors, while the sector of motor vehicles is more central through the lens of counting betweenness. Therefore, one could assume that the underlying meaning behind systemic importance of a sector suggests alternative results on potential of economic sectors to engender and propagate shocks.

Methods

In the study of shock propagation in international production networks of particular importance is the question of the main determinants of the cross-sectoral heterogeneity. It needs to be investigated if there are any patterns of the regions and industry mutual connections that make them amplify or mitigate propagation of shocks in production networks.

To identify the industry-specific patterns in shock propagation in European production networks the following hypotheses have been formulated:

H0: The differences in propagation of impact of sector-specific shocks on the European regions' outputs are determined by unknown factors.

H1: The differences in propagation of impact of sector-specific shocks on the European regions' outputs are determined by their spatial and economic position relative to other regions in production network.

H2: The differences in propagation of impact of sector-specific shocks on the European regions' outputs are determined by industrial diversification of regional economies.

To test the hypotheses, it is necessary to understand the network origins and mechanisms of shock propagation. In addition, a quantitative assessment of the regions' structural properties (namely, their mutual geographical and economic proximity, as well as industrial diversification) needs to be arranged. Finally, a classification of industries by patterns of shock propagation is performed. It is expected that sector heterogeneity is witnessed in the axes of tangible and intangible production, as well as industries' reliance on advanced infrastructure or broad networks of intermediaries.

Network mechanism of shock propagation

The conceptual approach to studying the effects of sector-specific shocks on the output of European NUTS2 regions in our paper is based on methodology proposed by Giammetti et al. [11]. The authors modelled extreme scenarios of breaking of production linkages of European regions with the non-EU countries by the so-called "hypothetical extraction" [9] (that is, by severing the rows and columns responsible for interregional flows in input-output tables). Despite its inability to precisely capture the network effects of breaking the linkages, this approach is a powerful tool for modelling shock propagation in production networks from the point of the amount of negative impact absorbed by a given region.

The first step of the analysis of shock propagation in international production networks is a specification of the main characteristics of firms participating in international production. The basic production function of a focal industry is represented by Formula 1. Here, y_i is an industry i's output, z_i stands for the Hicks neutral productivity shock, l_i is the labor force employed in sector i, x_{ij} stands for the amount of good j required for production of product i, $a_i > 0$ is the share of labor force under sector i's production technology, ζ_i is a normalizing constant which value is subject to the model's specification.

$$y_i = z_i \zeta_i l_i^{\alpha_i} \prod_{j=1}^{n} x_{ij}^{a_{ij}} \tag{1}$$

Carvalho and Tahbaz-Salehi [7] in their paper postulate that sector i's output depends on the production network's structure, as well as on the productivity shock for firms operating in j sector (Formula 2).

$$\log(y_i) = \sum_{j=1}^{n} \iota_{ij} \epsilon_j + \delta_i \tag{2}$$

In the Formula presented above ι_{ij} is an element of the Leontief matrix multiplier denoting all the possible routes connecting i and j sectors in a production network, ε_j stands for the logarithm of the productivity shock for firms from the j sector, δ_i is a constant independent to the shock.

The second theorem proposed by Carvalho and Tahbaz-Salehi suggests that the value-added in an economy is a derivative of productivity shocks in its separate sectors and the relative sectors' weights in an overall output (Domar weights) (Formula 3).

$$\log(GDP) = \sum_{i=1}^{n} \lambda_i \epsilon_i \tag{3}$$

Here λ_i is the Domar weight of sector i.

The theorems mentioned above allow one to articulate the two critical principles of shock propagation analysis that are significant for our paper. First, interregional multisectoral input-output tables provide sufficient information to study all the possible interconnections between industries in a production network. Second, the sectoral shock's impact for the aggregate region's output is proportional to the industry's weight in the regional economy's structure.

Modelling of sector specific shocks in European production networks

In the present study shocks originating from specific European sectors are modelled by 'hypothetical extraction'. This method implies 'zeroing' of rows and columns respective to a focal industry in the matrix of technological coefficients of input-output table. This way, it is assumed that the given industry curtails operations with other sectors and 'exits' from a production network.

The 'hypothetical extraction' makes it possible to model shock propagation in respect to both the suppliers of intermediates for this industry ('backward extraction') and the buyers of its products ('forward extraction').

The backward extraction for a given region-sector is executed according to Formula 4.

$$E_A = \mathrm{X} - (I - A_{cr})^{-1} f \tag{4}$$

In Formula 4 X denotes the vector of outputs of regions in a network, I is an identity matrix, A_{cr} stands for the matrix of input technological coefficients where rows and columns matching the extracted sector are 'zeroed', f is the vector of final demand for all the regions in a network.

As far as the buyers of a sector's products are concerned, the Formula of forward extraction will be the following (Formula 5).

$$E_B = X - V(I - B_{cr})^{-1} \tag{5}$$

Here, V represents the vector of value-added, B_{cr} stands for the matrix of output technological coefficients where rows and columns matching the extracted sector are 'zeroed'.

In this paper the absolute and relative values of the impact of sector-specific shocks on the regional output are calculated. The relative impact is estimated according to Formula 6.

$$E_{rel} = \frac{E}{X} \times 100\% \tag{6}$$

In our study, extraction is performed simultaneously for all the studied regions. The resulting variable under hypothesis testing is chosen to be the relative impact of sector-specific shock on the regional output, calculated as the ratio between the sum of all the absolute effects for all the sectors and the overall region's output.

Testing of sector heterogeneity hypotheses

The estimation of the correlation between the relative sector-specific shocks' impact and the regional position in the spatial system of intersectoral relations is based on the assumption that regions with higher spatial and economic centrality absorb, on average, a greater negative impact from such shocks. This may be reasoned by the fact that spatial concentration and agglomeration amplify the negative impact for central regions (that is, neighboring regions may transmit a portion of its effect to central regions).

The geographically weighted location quotient [18] has been applied to assess the impact of the spatial factor (Formula 7).

$$WLQ = Wy \tag{7}$$

Here, W denotes the nxn matrix of spatial weights, y stands for nx1 vector of location quotients LQ.

A single element of W spatial weights matrix is defined as follows (Formula 8).

$$w_{ij} = \frac{1}{{d_{ij}}^2} \tag{8}$$

In Formula 8 w_{ij} represents the spatial weight attributable to pair of regions i and j, d_{ij} stands for the distance between regions i and j in kilometers.

Location quotient is calculated according to Formula 9.

$$LQ_{pi} = \frac{x_{pi}/x_i}{x_{pn}/x_n} \tag{9}$$

Here, x_{pi} represents the output of sector p of a region i, x_i stands for the overall output of region i, x_{pn} is the output of sector p of all regions, x_n stands for the overall output of all regions.

The Herfindahl-Hirschman index has been used to quantify the degree of industrial diversification of a region (Formula 10).

$$HH_i = \sum_{p=1}^{n} {S_{pi}}^2 \tag{10}$$

In Formula 10 S_{pi} is the share of sector p's output in the overall output of a region i. The higher is the value of this index, the lower is the degree of industrial diversification of a given region.

Hypothesis testing is based on the comparison of the average relative shock effect for two pairs of region samples, namely A and B, as well as C and D. The A sample consists of the 10% of regions with the highest value of HH or WLQ index (separately for each indicator). Thus, the B sample is compiled of the rest 90% of the regions. In contrary, the C sample consists of the 10% of regions with the lowest value of HH or WLQ index (separately for each indicator). Thus, the D sample is compiled of the rest 90% of the regions. The two-sample t-test is applied to check the significance of the difference of the average relative shock effect separately for A and B samples, as well as for C and D ones (Formula 11).

$$H0: \mu_A = \mu_B$$
$$H1: \mu_A \neq \mu_B$$

Here, μ_A and μ_B represent the average values of shock effect for A and B, and C and D groups respectively. The t-statistics is calculated according to Formula 12.

$$t = \frac{\mu_A - \mu_B}{\sqrt{s_A^2/n + s_B^2/m}} \tag{12}$$

In Formula 12 s_A^2 and s_B^2 represent the sample variances of the shock impact for A and B (C and D) samples of regions, n and m are the sample sizes of A and B (C and D) respectively.

This test has allowed to group industries into four categories according to whether the relationship between the shock level and the specified indicator is evident or not. The first category comprises the sectors with a strong positive relationship (average regional decrease in industry's output is greater for regions with larger values of the indicator). The second group encompasses sectors with weak positive relationship (the positive relationship is only confirmed by either a single test, or an only one pair of samples). The third category includes sectors with negative relationship, and finally the fourth category comprises only industries that do not demonstrate any relationship between the shock impact and the specified indicator.

The information base of the research conducted was the interregional multisector EUREGIO input-output table for 2010 (the last available year in this database), covering 252 regions of EU-2006 and 12 sectors of the regional economy (the industrial classification is proposed by the project team) [17].

Results

According to Table 1, specific patterns of shock propagation are evident in several groups of economic sectors. For instance, the sectors of real estate, renting and business activities, as well as financial intermediation show strong positive correlation between the idiosyncratic shock impact and their economic and geographic proximity, and industrial diversification. The European regions that are more susceptible to spatial co-location externalities and have a low degree of industrial diversification capture relatively higher shock impact originating from the aforementioned sectors.

Table 1 – The results of two-sample t-test for the significance of mean difference for WLQ and HH

Type of correlation	WLQ	HH
Strong positive correlation	1. Real estate, renting and business activities 2. Financial intermediation 3. Coke, refined petroleum, nuclear fuel and chemicals etc.	1. Real estate, renting and business activities 2. Financial intermediation
Weak positive correlation (proved by one type of testing only)	1. Electrical, optical and transport equipment 2. Construction	1. Hotels and restaurants 2. Transport, storage and communications 3. Distribution
Negative correlation	1. Mining, quarrying and energy supply	-
No correlation	1. Agriculture 2. Distribution 3. Food, beverages and tobacco 4. Hotels and restaurants 5. Transport, storage and communications 6. Textiles and leather	1. Agriculture 2. Electrical, optical and transport equipment 3. Coke, refined petroleum, nuclear fuel and chemicals etc. 4. Construction 5. Food, beverages and tobacco 6. Mining, quarrying and energy supply 7. Textiles and leather

Source: Author

Regarding distribution sector that is the most critical sector for the overall output of European regions, it can be mentioned that the propagation of shocks originating from that sector is not subject to a region's susceptibility to co-location effects, whilst it is positively correlated with industrial concentration. Notably, mining, quarrying and energy supply sector demonstrates inverse interdependence of sector-specific shocks with a region's economic and geographic proximity. The testing shows that shock propagation in agriculture, food, textiles does not depend on the specified parameters of a region's economy.

Overall, there is a strong heterogeneity in shock propagation patterns among studied industries.

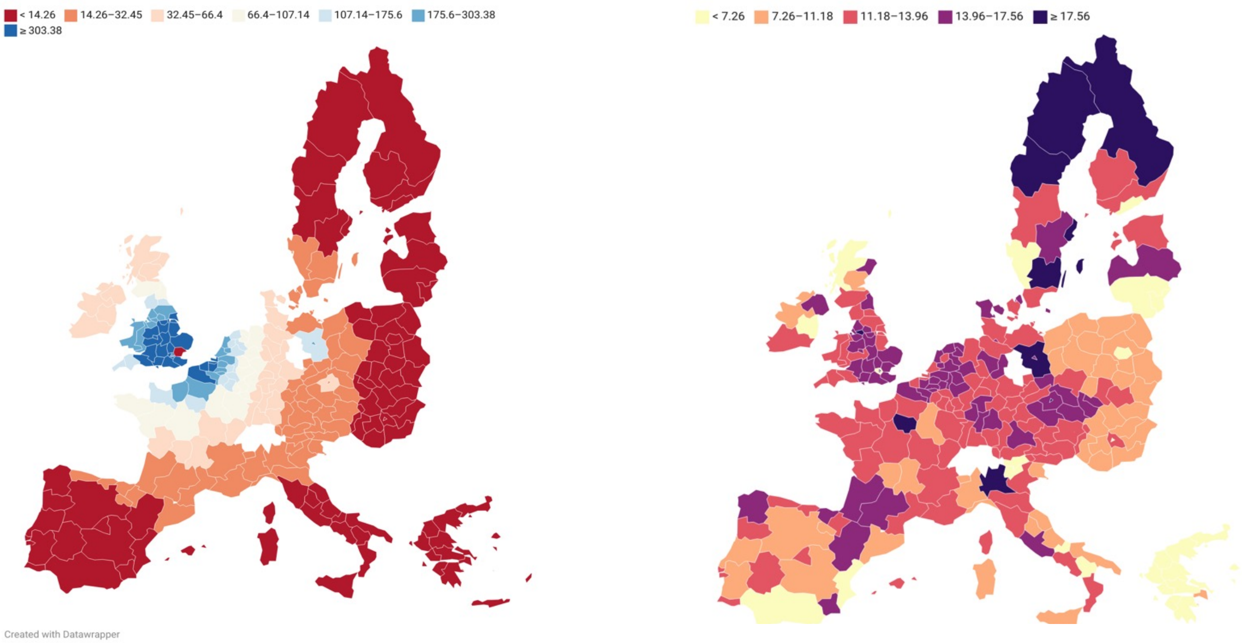
Hypotheses H1 and H2 receive empirical support for advanced services sectors that are essential for stable performance of the regional economy (Table 2). In general, H2 hypothesis is empirically supported only for services sector which implies that shocks origination in intangible production are most harmful for regions that have a narrow specialization. In other words, in industrially diversified regional economy shocks originating from services sectors are more evenly distributed between industries, which in turn contains the overall negative impact on regional economy.

Table 2 – Hypotheses testing for specified industries under study

No.	Industry	Hypothesis confirmed		
		H0	H1	H2
1	Real estate, renting and business activities		+	+
2	Financial intermediation		+	+
3	Coke, refined petroleum, nuclear fuel and chemicals etc.		+	
4	Electrical, optical and transport equipment		+	
5	Construction		+	
6	Mining, quarrying and energy supply		+	
7	Distribution			+
8	Hotels and restaurants			+
9	Transport, storage and communications			+
10	Textiles and leather	+		
11	Agriculture	+		
12	Food, beverages and tobacco	+		

Source: Author

More granular results can be obtained at the regional level analysis of shock propagation patterns in Europe. Particular attention is paid on the factor of geographic and economic proximity of regions as it represents the spatial distribution of business activities and their concentration around certain regions.

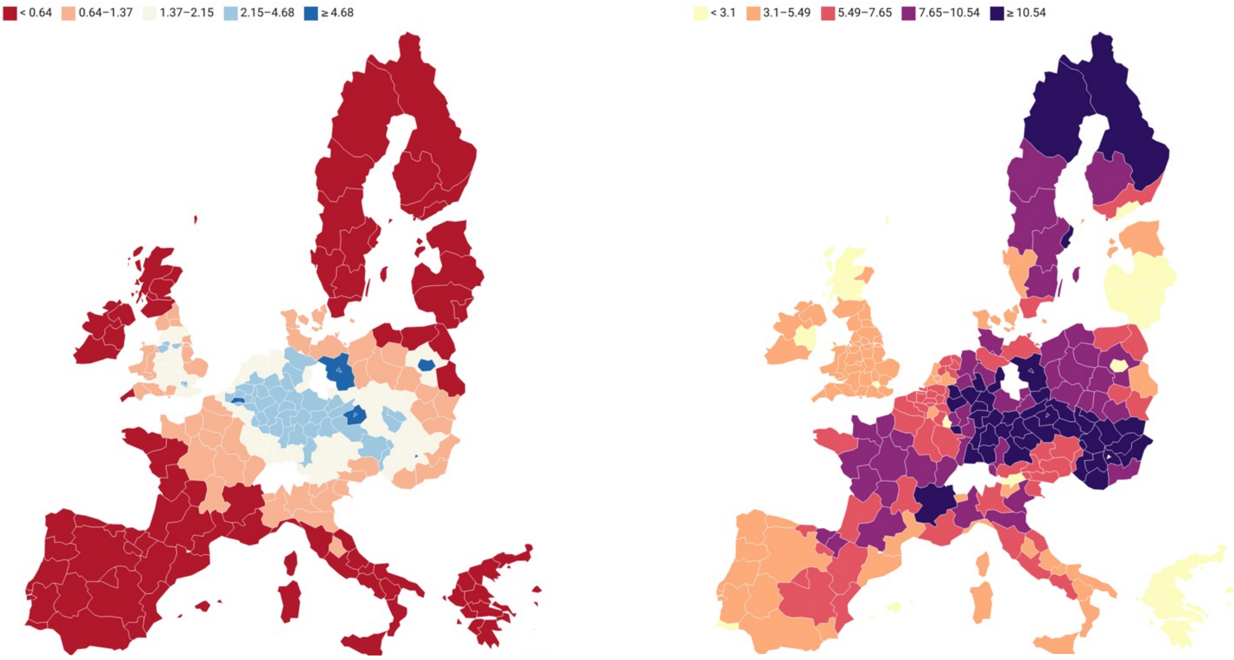


WLQ Shock impact (% of regional output)

Figure 1. Geographically weighted location quotient and backward shock impact for real estate, renting and business activities

Source: Author

In Figure 1 it can be seen that regions located nearby Pas de Calais bulk, separating the United Kingdom and France, share higher WLQ values and relative shock impact coming from the sector of business operations. By and large, the sector demonstrates strong spatial concentration around Pas de Calais bulk. While shock distribution generally follows the path of geographic distribution of business operation in the sector, several regions prove susceptible to such shocks (i.e., regions of Finland and Sweden, and Northern parts of Italy).



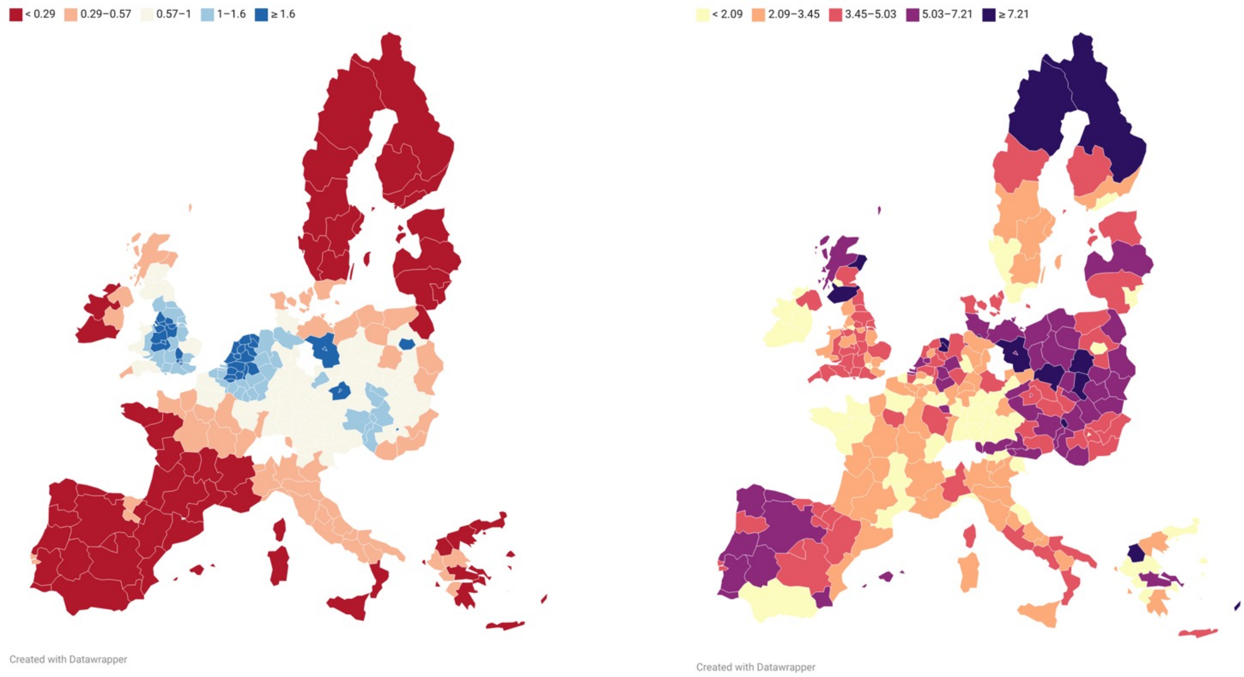
WLQ Shock impact (% of regional output)

Figure 2. Geographically weighted location quotient and backward shock impact for electrical, optical and transport equipment

Source: Author

Despite the fact that German regions have higher economic and geographic concentration of activities in electrical, optical and transport equipment, Czech and Slovak regions also demonstrate high relative figures of shock impact (Figure 2). Thus, the correlation between WLQ and shock impact in that sector is only partially verified. Considering the nature of production networks in European transport manufacturing, the observed phenomenon might be explained by a subordinate position of Eastern European countries to Germany as a leading economy in the industry [15]. Hence, Czech and Slovak regions, occupying relatively low-end operations (assembly, maintenance, simple component production) and thus possessing weak bargaining power in production networks, absorb a large portion of shocks originating from the industry.

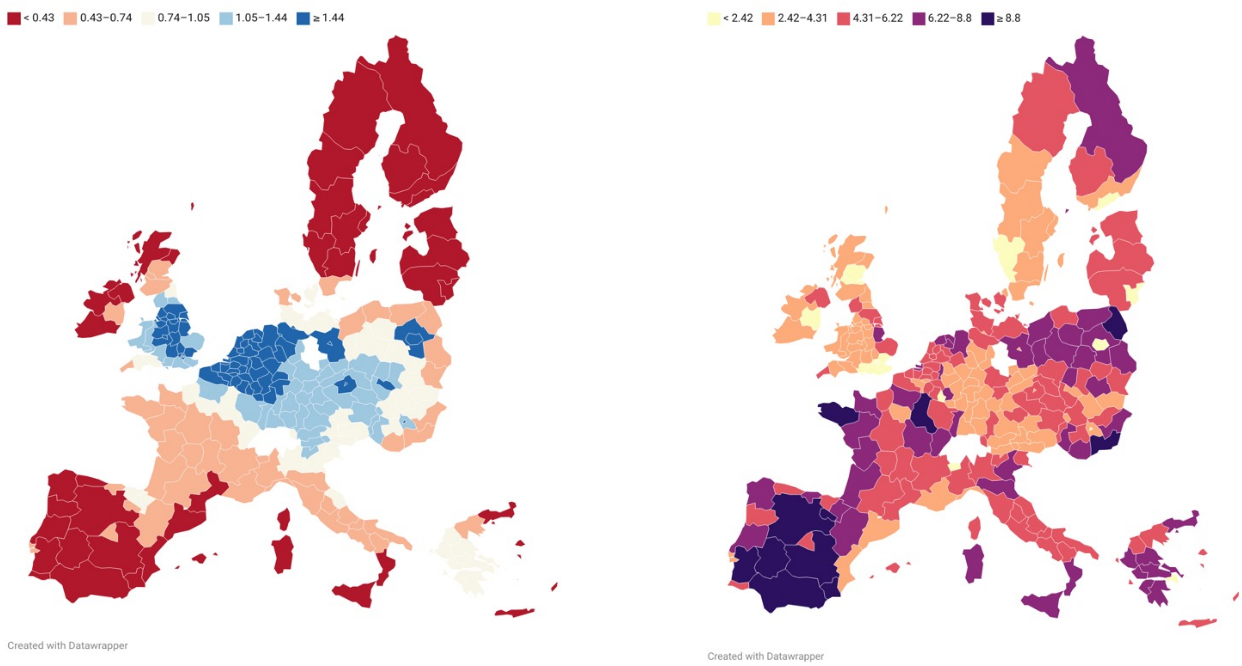
In 2010 the regions of the United Kingdom, the Netherlands, and Belgium were superior to other regions with respect to concentration of mining, quarrying and energy supply (Figure 3). At the same time, the highest relative shock impact produced by this sector was captured by Spain, Portugal and East Europe. This suggests an inverse relationship between the specified indicators for that sector. It is worth noting that the regions absorbing such shocks (apart from Finland and Sweden) primarily specialize in labor- and energy-intensive activities. Hence, their economic performance is largely dependent on foreign supplies of primary resources, which can be seen as a critical dependency in international production networks demanding state actions to increase self-sufficiency in energy and raw materials supplies.



WLQ Shock impact (% of regional output)

Figure 3. Geographically weighted location quotient and backward shock impact for mining, quarrying and energy supply

Source: Author



WLQ Shock impact (% of regional output)

Figure 4. Geographically weighted location quotient and backward shock impact for food, beverages and tobacco

Source: Author

The highest economic and geographic proximity in food, beverages and tobacco, according to Figure 4, is attributable to the regions of the United Kingdom, Germany, Belgium and the Netherlands. However, the regions of Spain, Greece, as well as West and East Europe absorb the largest share of negative impact from this sector. Here, a clear relationship between the specified indicators is not apparent. Yet one can assume that the WLQ calculation methodology used in our research may have an important limitation. In essence, it captures the level of concentration of value-addition in the industry, not the actual situation of productive capacities. Hence, if this indicator measured the second feature, the correlation might be positive since regions in Southern Spain, strongly hit by the shock in our model, traditionally specialize in this industry [10].

Discussion

Overall, the conducted empirical analysis has allowed to test the hypotheses of the research. Generally speaking, the results obtained match our prior expectations. Particularly, propagation of shocks originating from services sectors is dependent on the regions' economic and geographical proximity – the shock is transmitted in the form of 'concentric circles' hitting first regions closely tied with the main locations of value-addition in the industry. At the same time, shocks from tangible sectors do not possess universal features of propagation. In some cases, it reveals the intrinsic characteristics of international production networks, namely the mismatch between the geography of capacities and the geography of value creation in the same industry.

The strong positive association between shock level and economic and geographical properties of a region is most evident and valid in real estate, renting and business activities. According to the data collected, the 'center of mass' of this industry in the EU economy in 2010 was situated in Benelux countries, and in the UK. In part the revealed positive correlation between WLQ and a relative level of shock in the industry can be explained by the fact that provision of such services is associated with geographical concentration of firms. This ensures co-location and agglomeration positive externalities, as well as accelerates inter-regional flows of knowledge and innovations, which is essential for a stable performance of the industry.

At the same time, the business services sector is closely tied with other industries of a region, which enhances negative spillovers on other industries thus amplifying the overall shock impact on the region's economy. Positive correlation between absorbed amount of shock and HH indicator in this sector is largely determined by the level of economic sophistication of regions that specialize in real estate, renting and business activities.

A similar trend is observed in coke, refined petroleum, nuclear fuel and chemicals. One of the main specific features of the sector is high level of geographical clustering of production. In Europe the manufacturing of nuclear fuel and chemicals is largely localized in several regions of France and Germany. The technology used in the sector does not demand spatially distributed production networks. In addition, petrochemical industry greatly contributes to the regional product, and this in turn motivates positive correlation between negative shock impact and degree of regional industrial diversification.

The results obtained suggest that in several sectors, such as agriculture or textiles, no patterns of shocks propagation were observed. Such observation may be explained by the consideration that these industries are not critical for the economy of the most of EU regions. Besides, their technological process does not demand geographical co-location of productive resources, and it is mostly located in regions that traditionally specialize in these sectors (for food industry it is Spain and Eastern Europe, for textiles and apparel – Italy, Greece, and Portugal).

It is worth noting that in the majority of analysed cases the distribution of negative shock impact was asymmetrical. For instance, in electrical, optical and transport equipment the distribution was right-hand asymmetrical and leptokurtic. It suggests a presence of 'fat tails' in distribution of shock effect among analyzed regions, which in turn complicates an unbiased analysis of propagation of shock originated in this industry.

Last but not least, the research conducted revealed a duality in shock propagation depending on the region's specialization in a given industry. It has been shown that in services sectors such dependence is absent, which suggest a more stochastic character of shock propagation in these sectors compared to material production industries. In our opinion, susceptibility of services sectors to external production network shocks should be studied more carefully with an account of a growing role of services in the modern economy.

Conclusion

In the present study the problem of sectoral heterogeneity in shock propagation in international production networks has been studied. A special emphasis was paid to the case of European production networks that were dissected at the regional level for twelve industries covering both tangible and intangible activities. It has been tested if such heterogeneity in the case of Europe was determined by structural characteristics of regions, namely their geographic and economic proximity to other regions and level of industrial diversification of regions' economies.

The modelling of a shock occurrence in production network was based on the 'hypothetical extraction' method which implied a simultaneous breaking of production linkages between the given industry and the rest of the economy. To quantify the relative proximity of a region to other regions in the economy the weighted location quotient (WLQ) was calculated, whereby the ordinary geographical distance has been calibrated by the level of industrial specialization of the neighbouring regions. The level of industrial diversification of a region's economy was identified by calculating the Herfindahl-Hirschman index (HHI). Generally, it was expected that a region's susceptibility to production network shocks is weaker for regions that are more remote from the most specialized regions and/or which economic structure is more industrially diversified.

As the obtained results suggest, the correlation between shock impact on the region's economy and its economic and geographic proximity to other regions in the same industry is evident only in specific industries. Low industrial diversification of a region's economy amplifies shocks occurring in services sectors. Considering a growing role of services in the modern economy, maintaining resilience of the regional economy demands industrial diversification. Importantly though, shocks originating in labour-intensive industries (such as agriculture, textiles and food) do not follow some specific propagation pattern. Given their relatively small contribution to the regional product, such uncertainty does not imply significant problems for policymaking.

Important limitations of the conducted research need to be stated. First, the dataset used in empirical section is limited both temporarily and geographically. As a result, several countries that accessed EU in the recent years were not analysed, while all calculations were done on the 2010 yearly data. Second, the 'hypothetical extraction' method requires a strong assumption that the shock occurs simultaneously in all regions and a given industry completely breaks all production ties with other economic sectors.

As for future studies, we suggest that our estimations can be replicated on recent data to check the robustness of our results and potentially identify some additional patterns in shock propagation in international production networks. Apart from that, the role of industrial policy measures in promoting resilience of regions' economies can also be critically assessed by extending our research framework with inclusion of governmental support measures as explanatory variables.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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