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GLOBAL PRODUCTION NETWORKS IN THE REGIONAL ANALYSIS FRAMEWORK: CASE OF THE EU PERIPHERAL AUTOMOTIVE MANUFACTURING[1]

Abstract. Recent transformations following the global financial crisis of 2009, COVID-19 pandemic, supply chains disruptions and newest shocks have radically reshaped global production landscape and challenged comparative benefits of global production networks (GPN) vs global value chains (GVC) paradigms in international production analysis. The study tests the hypothesis that GPN concept allows for a better identification of structural shifts in international production structures while revealing regional patterns of cooperation. In the first section, the main methodological constraints of GVC paradigm are specified. Additionally, the reasons for the application of network-based approach to international production are outlined. The second section dissects the EU automotive manufacturing to support the theoretical propositions. While comparing GVC and GPN quantitative toolkits, the possible trade-off has been reached which is to calculate network indicators (transitivity, centrality, etc.) on the inter-country input-output tables. As a result, the hypothesis was confirmed. Specifically, betweenness centrality metric suggests that Czechia and Slovakia have immediately favoured a positive effect of the entry into the EU, whereas neither of GVC indicators reveals such a shift. Simultaneously, 2008 crisis is depicted via GVC indicators, whilst network metrics suggest no structural changes in the production system. These results corroborate to our theoretical juxtaposition of GVC/GPN approaches. The methodological cohesion of two sets of indicators further advances the views on European regional core-periphery integration and automotive production networks dynamics. At the same time, the findings may contribute to the reassessment of regional integration developments in Europe, as well as in Latin America and Eurasia.

Keywords: global value chains, global production networks, input-output tables, domestic value-added, total factor productivity, betweenness centrality, EU periphery, automotive manufacturing, clusterisation, slowbalisation

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ИССЛЕДОВАТЕЛЬСКАЯ СТАТЬЯ

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Региональный анализ глобальных производственных сетей: опыт автомобилестроения в периферийных странах Европейского союза

Аннотация. Экономические изменения вследствие глобального финансового кризиса 2009 г., пандемии COVID-19, сбоев в цепочках поставок и других потрясений привели к радикальной трансформации производственного ландшафта. Возник вопрос относительно сравнительных преимуществ парадигм глобальных производственных сетей (ГПС) и глобальных цепочек создания стоимости (ГЦСС) в анализе международного производства. В связи с этим была проверена гипотеза, предполагающая, что концепция ГПС позволяет лучше идентифицировать сдвиги, возникающие в международных производственных структурах, при этом выявляются региональные модели сотрудничества. В первом разделе рассмотрены основные методологические ограничения концепции ГЦСС, а также изложены причины применения сетевого подхода к анализу международного производства. Для подтверждения теоретических предположений во втором разделе была исследована сфера автомобилестроения в Европейском союзе. При сравнении количественных инструментов ГПС и ГЦСС был достигнут возможный компромисс, заключающийся в расчете сетевых показателей (транзитивность, центральность и т. д.) с использованием межстрановых таблиц «затраты — выпуск». В результате исследования поставленная гипотеза была подтверждена. В частности, показатель центральности продемонстрировал положительный эффект от вступления в ЕС для Чехии и Словакии, тогда как ни один из индикаторов ГЦСС не показал подобных сдвигов. В то же время индикаторы ГЦСС отметили влияние кризиса 2008 г., тогда как сетевые показатели свидетельствуют об отсутствии структурных изменений в производственной системе в исследуемый период. Полученные данные подтверждают теоретическое сопоставление подходов ГПС и ГЦСС. Методологическое единство двух наборов показателей позволило шире взглянуть на европейскую региональную интеграцию ядра и периферии и динамику сетей автомобилестроения. Результаты исследования могут быть использованы для переосмысления процессов региональной интеграции как в Европе, так и в Латинской Америке и Евразии.

Ключевые слова: глобальные цепочки создания стоимости, глобальные производственные сети, таблицы «затраты-выпуск», отечественная добавленная стоимость, совокупная факторная производительность, центральность, периферия ЕС, автомобилестроение, кластеризация, слоубализация

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1. Introduction

Contemporary studies in international production differ significantly in methodological propositions from international trade analysis at large. For one reason, this is motivated by growing volume of intermediate trade that does not follow the specifics of trade in final goods[1]. For another reason, complementary to the first one, technological advances have allowed for a higher specialisation mobility (Redding, 2002), whilst that has contributed to a wider shift towards path-defying changes in product space associated with higher gross domestic product (GDP) growth rates and overall industrial productivity (Coniglio et al., 2021). Narrow specialisation along with better exploitation of regional competitive edges and production interconnections between sparse localities are among the primary factors greatly influencing the mode of international production and its reflection in the literature.

Up to date, there are two main areas of research into international production and cooperation — global value chains (hereinafter — GVC) and global production networks (hereinafter — GPN). At the heart of the first paradigm is understanding of how the governance mode in the chain determines the production structure and which activities occupy central and higher value-added po-

[1] The World Trade Organisation. (2021). World Trade Statistical Review 2021. Geneva: WTO, 136. Retrieved from: https://www.wto.org/english/res_e/statis_e/wts2021_e/wts2021_e.pdf (Date of access: 10.01.2022).

sitions in GVCs (Gereffi & Fernandez-Stark, 2011; Shin et al., 2012). Concerning GPN paradigm, its analysis is largely concentrated on the concepts of value, power, and embeddedness with a particular notion of territorial development dynamics (Coe & Yeung, 2015; Coe et al., 2008). At the same time, global production networks in their definition are continuously intersected with international production networks (Cingolani et al., 2018) since it is only at an aggregate level where it is feasible to properly apply network framework for this analysis.

It is worth mentioning that GPN paradigm appears to be more promising as it provides the researchers with a multi-dimensional picture portraying production linkages. In times of economic turmoil and prevailing external shocks this opportunity allows firms to establish alternative collateral cooperative structures in order to maintain their production.

In this paper we aim to argue the key methodological advances of GPN theory and its empirical implications to the analysis of regional automotive European Union (EU) networks. Our empirical study is two-fold. First, we pay closer attention to GVC indicators to briefly describe the relative positions of these countries in a system of global automotive production. Second, we estimate network-based indicators to demonstrate the relative position of these countries' industries in the EU automotive sector. Unfortunately, we had to rely on industry-level indicators while calculating network indices, which is a significant deviation from GPN paradigm. Even though, we still believe that such indicators can broadly and more correctly explain some current trends and shifts in EU peripheral automotive manufacturing.

2. Literature Review and Theoretical Framework

2.1. Global Value Chains Methodological Propositions

Conceptually, there are four critical factors ('casual drivers') that determine the structural position of the entity in the spatial production structures: cost-capability ratio, market imperative, financial discipline, and risk management (Yeung & Coe, 2014). The drivers that have been listed before suitably line with the concept of spatio-temporal fix (Jessop, 2005) that is described as 'a metaphor for solutions to capitalist crises through temporal deferment and geographical expansion'. It does not clarify how exactly the spatial production is formed and what pushes the lead companies to conceptually rearrange their production chain upscaling the value creation over the whole system. Here we share the view of Baldwin and Venables (2010) that it is technology, namely the engineering of the production process, that ultimately determines the interlinkage of separate stages. The key narrative behind this is that technology follows the consumers demand to satisfy their daily needs on a more comfortable level leaving aside the personal involvement in both the work and home routine. This way, 'smarter goods' should comprise more and more functions becoming more sophisticated and less holistic.

Unbundling prescribes a new international trade pattern that takes account of not final, but intermediate goods and services which serve as 'bricks' forming the final product. Particularly, GVC methodology focuses at trade in intermediates. 'Value' attribute of GVC methodological space stands for the process of value addition on each stage of production, be that the first processing of petroleum or post-production maintenance. 'Trade in value added' (TiVA) term has been introduced to the practice as a new international economic statistical paradigm that involves a set of indicators each showing how much value added is embodied into a country's exports / imports with a breakdown into separate industries. The main source of value-added data on a global scope are OECD's Inter-Country Input-Output (ICIO) tables that are computed in spirit of Leontief Input-Output methodology[1].

Research into structural change dynamics has been enhanced with the application of trade in intermediates, which has enabled transition towards analysis of the open economy, instead of autarky (Stijepic & Wagner, 2012). The authors have demonstrated that the productivity-growth-effect induced by intermediate trade is associated with relatively high rate of savings and capital accumulation in open economy, contrary to autarky. Thus, advances in intermediate trade analysis have contributed to a better understanding of long-term trends in labour reallocation.

The impact of intermediates inputs increase to Latin America on its final and intermediate goods exports growth was also investigated (Florensa et al., 2015). It was found that intermediate imports from China had been associated with positive effects on the regional production system indicating the formation of spatial production structures.

Furthermore, the small developing countries can also provide a relevant experience of how the

[1] OECD. (2022). Trade in Value Added Database. Retrieved from: https://www.oecd.org/sti/ind/measuring-trade-in-value-added.htm (Date of access: 10.01.2022).

trade in intermediates as the main channel of participation in GVC stimulates the company productivity growth in manufacturing. The case study of Uruguayan manufacturers focuses on disentangling the impact of liberalised access to intermediate input from that of technology transfer (Zaclicever & Pellandra, 2018). Namely, the authors elaborate on a dataset of 855 different local companies with 50 or more employees in the period 1999–2008. Approximately 48 % of intermediate inputs of these companies originate from MERCOSUR. Productivity gains are captured in the paper by estimation of total factor productivity OP (Olley and Peaks) augmented version. The results of the study suggest that there is evidence of a variety effect for inputs from MERCOSUR, while for inputs originating from advanced economies the productivity enhancing effect is associated with inputs' technology content.

Finally, intermediate input statistics were examined to calculate two another important measurements of GVC participation — upstreamness and downstreamness (Antras & Chor, 2018). The authors have further analysed the evolution of these two indicators over the period 1995–2011. Interestingly, it has been shown that country-industries that are far removed from the final demand also tend to be far removed from the use of primary factors for production. ICIO (or alternatively World Input-Output Tables (WIOT)) methodology here has also served as the key GVC measurement paradigm whereby authors came closer to understanding of not just the effects of intermediate trade on company productivity, but also of what important phenomena explain relative position of industries in GVCs. Nevertheless, such a reliance on the aggregate tables and models while taking no notion of the business environment factors pushes one forward to determine important limitations of this methodology (as presented in Table 1).

The mentions of upstreamness and downstreamness are further related to the analysis of the value moving along the chain itself. A concept of 'snakes' and 'spiders' (Baldwin & Venables, 2010) has become widely recognised. This concept is more preferably used while studying the manufacturing sector. The latter term perfectly fits what has been touched upon before: 'snake' refers to 'the good moving in a sequential manner from upstream to downstream with value added at each stage'. By 'spiders', on the contrary, one means 'multiple limbs coming together to form a body (assembly), which may be the final product itself or a component (such as a module in the auto-industry)'. The authors intend to illustrate how the motives of cost-minimisation, as well as the influence of the location of the final demand destination, assembly plant, and another counterpart, differ in both structures, when the value is added sequentially ('snakes') and when the final product is ultimately composed of a set of inputs from the suppliers of equal order ('spiders'). This approach is thus a step forward in the truly spatial dimension of GVC analysis.

The critical pillar of GVC analysis is the study on the role of standards in the formation and coordination of separate productive units. Obviously, in the real world, cost-minimisation motives are multifarious since the management takes care of not only cost-capital and operation profit ratios, but also of the costs induced by transaction motives and supplier-switching decisions that lay in the field of principal-agent theory (Zhang et al., 2015). The way the whole chain is operated depends on the specific standards set by the lead firm. This is perfectly seen in buyer-driven chains, such as Nike or Reebok production chains (Gereffi & Fernandez-Stark, 2016). Moreover, by the standards one can assume the so-called 'non-tariff barriers to trade' which are, generally, technical standards, prescriptions, and regulations on the contents of some certain goods[1]. The main yardstick of their impact is ad-valorem equivalent (hereinafter — AVE) that is calculated as an additional margin that makes the imported inputs more expensive (Disdier & Fugazza, 2021). Basically, AVE represents the relative difference in domestic and world prices of the product that is imported adjusted for tariff and transportation costs. According to the study of Beghin et al. (2013), for the XVII group of the Harmonised System (vehicles, aircraft, vessels) NTM AVE, on average, equals to 0.035. Thus, roughly speaking, with 'unbundling' taking place, each additional production stage ceteris paribus rises the price of the inputs by around 3,5 % in the automotive sector. There is a dilemma in GVC analysis: more international standards, less switching supplier and transaction costs, but more costs associated with the production itself. And this is by far the cornerstone of why there is still no clear research agenda on the role of international standards.

Regarding the study of lead companies' productivity, there is a growing number of papers that explain how the performance of major companies in GVCs is shaped by both inter-firm and relational governance, and also cultural distance

[1] UNCTAD. (2022). Classification of Non-tariff measures (NTMs). Retrieved from: https://unctad.org/topic/trade-analysis/non-tariff-measures/NTMs-classification (Date of access: 26.02.2022).

Table 1

Opportunities and limitations of GVC quantitative methodology

Quantitative method	Dimensions	Opportunities	Limitations
ICIO	Country	Compliance with the systems of national accounts Applicability to informal macroregional integration analysis Higher data accuracy	Lower geographical reliability (core production clusters are usually concentrated in a very limited area, not dispersed among the country) Insufficient notion of specific territorial productive assets Exaggeration of geographical location and neighbourhood (namely, when the country acts as a transit destination, whereby statistically favouring higher intermediate inputs and outputs values than it practically deserves)
	Industry	The data is verified and suitably formed by the industry-level authority Economic sectors are universally encoded in the international trade classifications The possibility to analyse the relative impact of a certain industry on the whole economic performance	Some industries are highly subsidised by the government; thus, it can be nearly impossible to record their real performance The industry can be highly concentrated, which makes it impossible to draw conclusions on the position of relatively small companies in the sector Production structure of the industry is not properly considered
	Large-scale table	All the possible locations and industries are covered by the ICIO tables	Some locations do not necessarily have a clear specialisation in each sector, but are still taken into consideration, which distorts the conclusions
	Value-added as a resulting indicator	Value-added reflects the relative contribution of the industry to the overall industrial upgrading of the economy The domestic value added / foreign value added (DVA/FVA) ratio illustrates the position of the industry in a relevant GVC	The most portion of value-added can be generated by a handful of companies, while the other are unprofitable or subsidised Value-added perfectly demonstrates the overall productive capacity of the industry, but does not illustrate the value distribution among the companies involved in the sector
TFP	Olley-Peaks extension	Overcoming of the problem of the correlation between the import decisions of companies and unobserved productivity shocks The approach allows to capture the company-level productivity effect of intermediate input along with the factor intensity (capital, labour, energy consumption)	Broadly, this approach only supports the view that international trade is a positive source of productivity upgrading for small developing countries; though, it does not clarify the key patterns of their inclusion into international production system
	Malmquist Productivity Index	Captures the changes in overall industry productivity caused by both catching up (better usage of existing technology) and innovation (reaching a higher productive potential by improving existing technologies) Account of the research and development (R&D) transmission and FDI flows through import channel	Statistically, it can only be applied for a country-level analysis

Source: authors' elaboration with (Haider et. al, 2020; Zaclicever & Pellandra, 2018).

and product modularity. In attempt to apply the OLI paradigm[1] to GVC analysis, it has been concluded that the further research into GVC perspectives may be carried out in three directions: the orchestrating role of the lead company, the

[1] One of the most respectable concepts in International Business studies that is broadly used to explain foreign value-added activities of the MNEs in terms of their geographic dispersion, the patterns of interactions with local units, and the extent to which the MNE is ready to externalise its operations. O stands for ownership advantages, L — locational advantages, and I — internalisation advantages, respectively.

network-dependent position of the lead company, and in the field of integrated theories of network control. Moreover, now it is widely admitted that, apart from three already existing advantages in the OLI methodology, inclusion of so-called 'network advantages' also deserves attention from the community (McWilliam et al., 2020).

It becomes apparent that, while analysing the moving of value along GVCs, it is nearly impossible to stick to the line of linearity and statistical aggregation. Upstreamness and downstreamness face the pressure of the 'snakes' and 'spiders' structures specifics, where one already exceeds the linear narrowness. The notion of standards could possibly reinforce the need to study the linear process of costs multiplication caused by NTM burden. But even in the case of standards, there is no clarity of their effect on overall lead company productivity and GVC formation patterns. But, when synthesising with co-evolving and gaining its popularity IB analysis, it becomes clear that such a governance shall be analysed in a firm cohesion with network-specific advantages of geographically and culturally dispersed local units. Thus, there is a commonly held view that the modern internationalised production systems cannot be fruitfully examined with no sufficient notion of the whole system of inter-firm relationships presented as a network structure, as well as other actors and factors that directly or semi-directly influence the way the production is organised and the options for local producers to enter these systems.

2.2. Global Production Networks. The Introduction of Network-Based Analysis

In comparison to GVC paradigm, GPN approach reveals additional methodological advances. First, it allows for the relational analysis of the value-creation process instead of the additive one. Second, it considers the network culture phenomenon as an opposition to the power-dependence dichotomy. Finally, GPN approach give birth to the second topological dimension (non-linear, spatial).

According to the key designers of the GPN theory Coe and Yeung (2015), the GVC concept, as well as adjoining schools of thought that laid the foundation of GPN theory, lack the following passages that are furtherly discussed under GPN agenda. First, while putting inter-firm relationships in the corner, GVC paradigm did not fully embrace the analysis in extra-firm actors (i. e., trade unions, governmental agencies) interactions. Second, GVC perspective has steadily foregrounded national and global level of coverage, thus lacking multi-scalar view. Apart from that, the governance patterns themselves are much more sophisticated, multivariant, and changing over time than it is presented in GVC/GCC analysis. Finally, and it has been previously mentioned in our own consideration, 'production systems are seen as networked and recursive meshes of intersecting vertical and horizontal connections'. The GPN theory relies heavily on this proposition 'in order to avoid deterministic linear interpretations of how production systems operate and how value is generated and distributed' (Coe & Yeung, 2015).

We should take account of the fact that this new analytical roadway requires considerably more explicit sub-national level statistics. Provided such a dataset is compiled, the results obtained may be much more reliable and illustrative. Thus, the study of the large dataset of almost one million Japanese companies contributed to a better understanding of how production network structure influences company performance (Bernard & Moxnes, 2018). Overall, the sampling consisted of 961 thousand companies acting as network nodes and 3783 thousand supplier-customer connections (i. e., directed edges). It has been shown, for instance, that large and more productive Japanese companies, on average, have more suppliers, although these suppliers are less-well connected themselves (negative assortativity) and are located farther away.

A possible trade-off between network methodology and GVC toolkit can be achieved by application of centrality and degree indicators to country-industry level. On that path the concept of international production networks (hereinafter — IPN) was developed (Cingolani et al., 2018) as a basis for identifying endogenous geographical subnetworks based on preferential trade links and examining the topological structures of the trading regions to assess whether they have some similarities across industries and if they are built around a core country. By applying revealed trade preference indices, as well as clustering coefficient and degree centralisation, it has been proved that a stronger preferability and selection of trade partners seem to take place in intermediate trade, which perfectly fits the theory of international fragmentation of production.

Taking a closer look at GPN 2.0 paradigm, territoriality dimension of analysis appears to be even more productive. As Coe and Yeung (2015) point out, the previous consideration of territoriality under GVC framework as consisting of simply core (developed) and periphery (developing) countries is challenged by GPN paradigm which grasps territoriality as a mechanism of the anchoring of di-

vergent actors in production systems in places and regions. The lower scale of territorial analysis is crucial for conceptualising both the organisational dynamics and, specifically, development outcomes that are seen as the key object of preparation in GPN 2.0.

Production networks in the recent decades have naturally entered the broad avenue of the network research. Although, as it goes from other economic network studies (namely, financial) (Macchiati et al., 2021), density and interwovenness of spatial structures may, in turn, propagate internal shock (such as, systemic risk in the financial system).

For a better clarity, it must be admitted that hitherto there is a serious ambiguity with how to label the spatial systems of production. Specifically, GVC term is still more widespread in the broad industrial studies and economic geography community. Despite this obscurity, it is still worth pointing out that these indicators are estimated on WIOT indicators, which we have covered earlier. But, for us, it remains clear that such elaborations can fruitfully enlarge the analytical space and lead to the more consistent results. The OECD researchers estimated centrality measures, namely Bonacich-Katz eigenvector centrality, to determine on the country-industry level which sectors are influential in global production networks, and which exhibit weak linkages with other sectors (Criscuolo & Timmis, 2018). According to the study, Japanese total GVC participation (both forward and backward) over the period 1995–2011 has increased by 18 % of gross exports, while its centrality has declined for almost 50 % for the same period with declines in most of the manufacturing and service sectors. The authors conclude that such a tendency is primarily determined by a weakening role of Japan as a customer and supplier of intermediates within Asia. This finding perfectly illustrates the central idea of centrality measure which is that the power of a unit in the network should be assessed only in relation to another units.

Several studies have explored specifically the regional and global dimensions of automotive networks (Gorgoni et al., 2018). The authors extend the scope of network analysis of automotive production by application of the broadly known E-I index. By and large, topological analysis allows one to scrutinise the inter-firm relationships between key GPN actors (lead companies, strategic partners, specialised (industry-specific) suppliers, generic suppliers, and key customers) (Yeung & Coe, 2014). Second, topological analysis based on the graph theory substantially contributes to the better understanding of the resilience of the production structures. In a theoretical mini-review (Schaeffer et al., 2021), the structures as 'common strategic partner' and 'common specialised supplier' are indirectly referred to as triangular lattice (TL) and linear ladder (LL), respectively. In theory, the first structure should demonstrate higher level of resiliency and be more capable of withstanding external shocks. But, in reality, the situation is different. Namely, TL structures are attributable to the ITC industry where several original design manufacturing (ODM) and electronics manufacturing services (EMS) providers can serve the needs of multiple brand name lead companies. Thus, shocks occurring in one of such central players can harm severely the whole sector. Third, the spatial topological analysis provides the opportunity for inclusion of local assets and competitive advantages into the study of production structures and welfare outcomes. This notion resonates with the theory of territorial capital (Capello et al., 2020) where territory is defined as a system of localised production activities, traditions, skills, and know-hows. GPN 2.0 paradigm unambiguously puts into the focus of attention the territorial developmental outcomes based on GPN configurational patterns. That is why the intersection of territorial capital theory and GPN paradigm can be a step forward in the study of international production and upgrading.

3. Data and Methodology

Here in this study, we theoretically and empirically distinguish between GVC and GPN methodological propositions and limitations. Specifically, in the previous section we have heuristically explained why we consider GPN methodological toolkit (namely, relational profile of the production network and, respectively, network embeddedness as a concept) a promising source of relevant takeaways on how the network actors interact with each other and what general attributes do production networks share with those described in the traditional graph theory).

Our comparison is also supported by quantitative analysis of the key GVC and network-based indicators (Newman, 2018). Broadly speaking, the participation in GVCs is tracked down by a set of indicators calculated around three main dimensions — country/region (the production country, value added source country, etc.), industry, and supply/demand (intermediate, final, or total goods and services). For our study we decided to focus primarily on two highly illustrative metrics. The first one is domestic value-added content of gross exports (*EXGR_DVA*), which measures the overall

effectiveness of domestic industry in spatial production presented by the whole additional value generated in the sector that is furtherly exported down the chain (Formula 1).

$$EXGR\_DVA_{c,i,p} = \\ = V_c B_{c,c} \sum_p (EXGR\_INT_{c,i,p} + EXGR\_FNL_{c,i,p}), \quad (1)$$

where $EXGR\_INT_{c,i,p}$ is the gross exports of intermediate goods and services from domestic industry i in country c to partner country p and $EXGR\_FNL_{c,i,p}$ is the gross exports of final demand goods and services, where c and $p \in [1, .., N]$ and $c \neq p$.

Another important indicator which better explains the patterns of inter-industry exchange between the industries is domestic value-added in exports of intermediate products as a share of total gross exports (EXGR_INTDVASH) (Formula 2). Basically, it is widely regarded as a measure of forward linkages in global value chains.

$$EXGR\_INTDVASH = \frac{\sum_p EXGR\_INTDVA_{c,i,p}}{\sum_p EXGR_{c,i,p}}. \quad (2)$$

Here $EXGR_{c,i,p}$ is the gross exports from domestic industry i in country c to partner country p.

Concerning network-based indicators, it is worth noting that they reflect both the overall network performance, the extent to which the network is dense and the nodes are evenly distributed, and also the relative position of the node in the system based on its importance as an intermediary between another vertices.

In our analysis, we consider it important to portray the general structure of the EU automotive manufacturing first, and then to assess the position of the nodes representing Poland, Czechia and Slovakia in it.

The first indicator representing the relative share of already existing edges to the maximum possible number of them is graph density (Formula 3).

$$density = \frac{a}{N(N-1)}, \quad (3)$$

where a is the number of existing linkages in the graph and $N(N-1)$ is the number of total possible relations. This metric allows one to assess whether the network is heavily interconnected, or the nodes are generally connected with a limited number of partners.

Additionally, it might be beneficial to analyse the interdependence of the nodes in the network since ICIO tables present both input and output connections between industries. This can be captured by the reciprocity metric illustrated in Formula 4.

$$reciprocity = \frac{L^{<->}}{L}, \quad (4)$$

$L^{<->}$ stands for the number of links pointing in both directions, while L is the total number of links.

Regarding the nature of automotive production, we consider it significant to take a closer look at whether there are large conglomerates in the industry, or the nodes are connected to each other more evenly. The transitivity metric is thus important for this purpose (Formula 5). It is calculated as the relative number of triangles in the graph, compared to the total number of connected triples of nodes (clustering coefficient).

$$transitivity = \frac{3 \cdot T}{C}, \quad (5)$$

where T is the total number of triangles in the network and C is the total number of connected triples of nodes in the network.

As we pointed out before, relative position of the nodes representing peripheral economies should also be carefully studied. In our opinion, betweenness centrality (see Formula 6) is a relevant indicator in that sense as it measures the number of shortest paths that pass through the vertex. The higher the value of this metric, the more important the vertex is in terms of its significance as an intermediary in the network.

$$betweenness\,centrality = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}. \quad (6)$$

Here σ_{st} is the total number of shortest paths from node s to node t, $\sigma_{st}(v)$ is the number of those paths that pass-through v, where v is not an end point.

The quantitative analysis is conducted on the EU peripheral automotive manufacturing, which is represented by Poland, Czech Republic and Slovakia. Our primary goal is to compare the figures derived from the calculation of the aforementioned indicators and identify what network-based indicators add up to the traditional conception of the position of EU peripheral economies in automotive sector. The value-added indicators have been extracted from the OECD Trade in Value-Added database, which is formed on International Standard Industrial Classification (ISIC) Revision 4. The automotive production here is presented by 29th (manufacture of motor vehicles, trailers, and semi-trailers) and 30th (manufacture of other transport equipment) divisions. To estimate network-based metrics, we used the OECD Inter-Country Input-Output (ICIO) tables

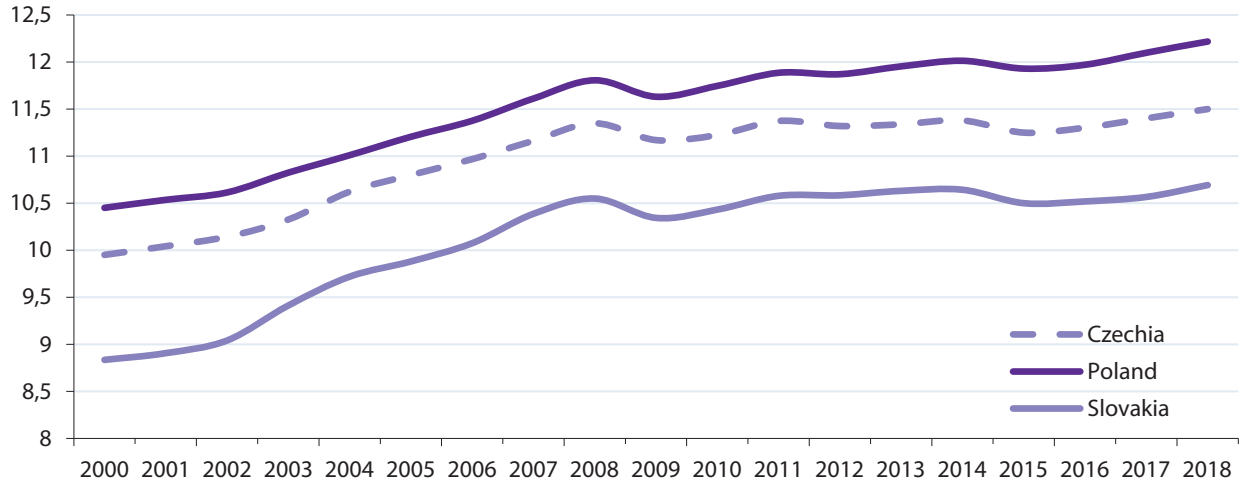

Fig. 1. *Domestic value-added content of gross exports (logarithm from the absolute value, 2000–2018). Source: authors' elaboration*

that follow the same industrial brake-down. The interval chosen is 2000–2018. Specifically, we pay attention to 2004 when these three countries entered the EU. The network calculations have been carried out with the use of 'igraph' package for *R* statistical environment. Aiming at gathering only relevant data for our analysis, we modified ICIO tables so that only nodes ($Xi_{i,j}$) representing the 29 and 30 ISIC divisions for EU countries (54 at all) would leave. Since ICIO tables consist of intermediate product flows, it is important to take account of both the forward ($X_{1,1}$ to $X_{2,2}$) and backward ($X_{2,2}$ to $X_{1,1}$) linkages as they may differ significantly. Then, to make an adjacency matrix, we assumed that the link between the nodes exists if the flow from one node to another exceeds 1 million dollars a year.

4. Results

4.1. EU Periphery in Automotive Global Value Chains

Concerning the analysis of GVC indicators, we can formulate the following hypothesis: over the analysed period, the overall domestic value added in the industry's exports shall rise significantly and the economies shall transit more towards backward GVC participation. The calculations of GVC indicators are presented on Figures 1 and 2.

According to Figure 1, the overall DVA content of gross exports is growing in all three countries, suggesting that the analysed economies constantly upscale their contribution to the subsequent stages of the production chain and do not rely on import substitution in the sector. At the same time, the relative pace of the DVA and FVA growth portray dissimilar trends. As it follows from Figure 2, Czechia is demonstrating the relative contraction of DVA share in its intermediate exports in automotive manufacturing. Thus, the growth of FVA component is outstripping the growth of DVA. This way, it can be interpreted as a promising sign for the further development of Czechia's automotive production since its GVC participation in European automotive sector deepens, becoming more diversified. Overall, judging only by these metrics, it is barely feasible to draw verified conclusions on the position of the EU periphery in the world and, specifically, Europe automotive manufacturing (i. e., these indicators cannot be calculated for the intra-regional trade).

4.2. EU Periphery in Regional Automotive Production Network

We have carried out a set of modelling operations which revealed that over the time, the relative size of the nodes in European automotive networks smooths out. In other words, large core economies, such as France or Germany, are no longer the only influencers in the network. Additionally, in 2000, the trade has been divided between 29 and 30 ISIC divisions, which almost did not trade between each other. Then, towards the middle of the period, the situation has changed: two divisions have tightly intertwined and traded easily between each other. But then the dynamics went the opposite way: two divisions began to cluster with the nodes representing the same division. This tendency can be treated as negative for the EU periphery since all these economies are heavily reliant only on 29 division.

Next, we analyse density, reciprocity and transitivity metrics of the whole EU automotive production network (Figure 3).

The sustained growth of the density metric suggests that the intra-industry cooperation in

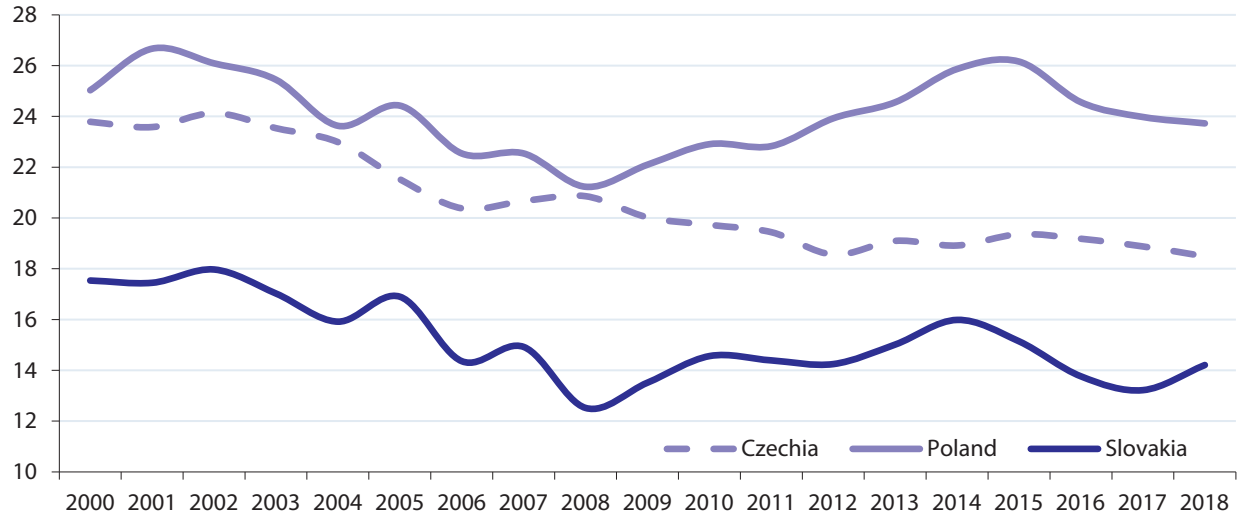

Fig. 2. *Domestic value-added in exports of intermediate products as a share of total gross exports (ratio dynamics, %, 2000–2018). Source: authors' elaboration*

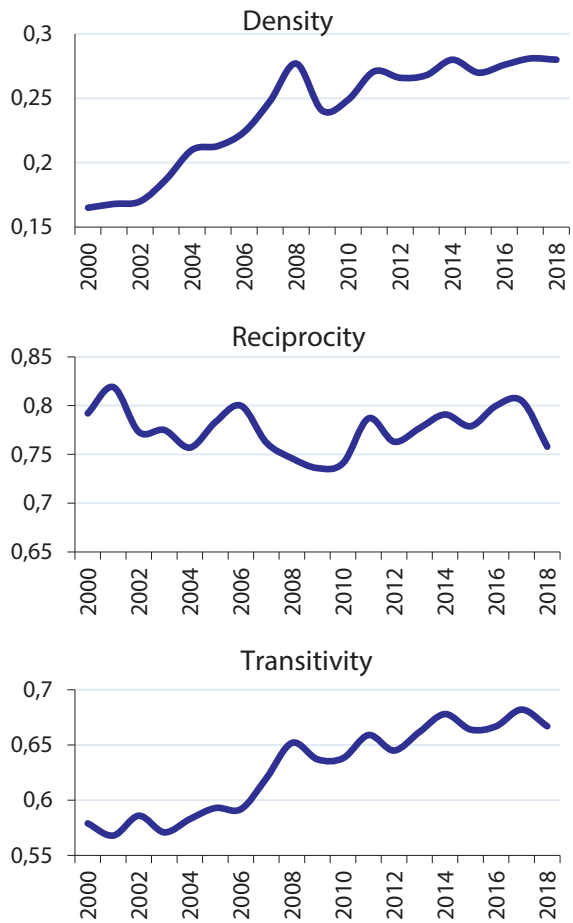

Fig. 3. *EU automotive production network density, reciprocity, and transitivity metrics (left to right). Source: authors' elaboration*

EU automotive sector is developing and that more and more economies collaborate closer through the intermediate trade.

It is important to mention that the variation of reciprocity is in the region of 0.74–0.82, which is a relatively narrow window. This way, considering the rise in the density estimation, this small variation of reciprocity suggests that, on average, some new linkages in the network appear two-directional right away. So, when the new industry firmly enters the EU automotive production network, it certainly will play the role of an important input and output supplier, which further makes the whole network more resilient.

There is also a strong clustering tendency in the EU automotive manufacturing. The similar nodes in this network tend to connect with each other more vividly over time. Possibly, this tendency is a sign of the deepening divide between the core and the periphery, but this assumption requires considerably more testing.

In the final section of the paper, we focus specifically on the nodes matching the EU peripheral countries both in 29 and 30 ISIC divisions. The density metric characterised above can also be computed for a so-called 'subgraph' (Table 3) which is basically a graph of the closest nodes to the given vertex representing the most important connections of this specific node.

It becomes apparent that for 29 division there was a definite slowdown over 2000–2013, while, later, the density has returned almost to the previous levels. Slovakia's case is very peculiar in that sense. The density of the connections of its motor vehicle production has been lowering, while the presence of the economy in the equipment sector was firming.

As long as peripheral economies in the EU are much more concentrated over the production of motor vehicles, rather than over equipment, it is worth considering betweenness centrality of their nodes for better understanding of their relative

Table 3

Subgraph of the density for the automotive production networks of EU peripheral countries (2000–2018)

Year	Czechia 29	Czechia 30	Poland 29	Poland 30	Slovakia 29	Slovakia 30
2000	1.72	1.80	1.37	1.50	1.95	0.00
2004	1.28	1.44	1.50	1.37	1.56	1.67
2007	1.18	1.59	1.36	1.31	1.48	1.75
2010	1.14	1.25	1.34	1.12	1.29	1.82
2013	1.15	1.68	1.16	1.32	1.31	1.89
2016	1.26	1.71	1.36	1.24	1.43	2.00
2018	1.14	1.61	1.19	1.20	1.40	1.89

Source: authors' elaboration.

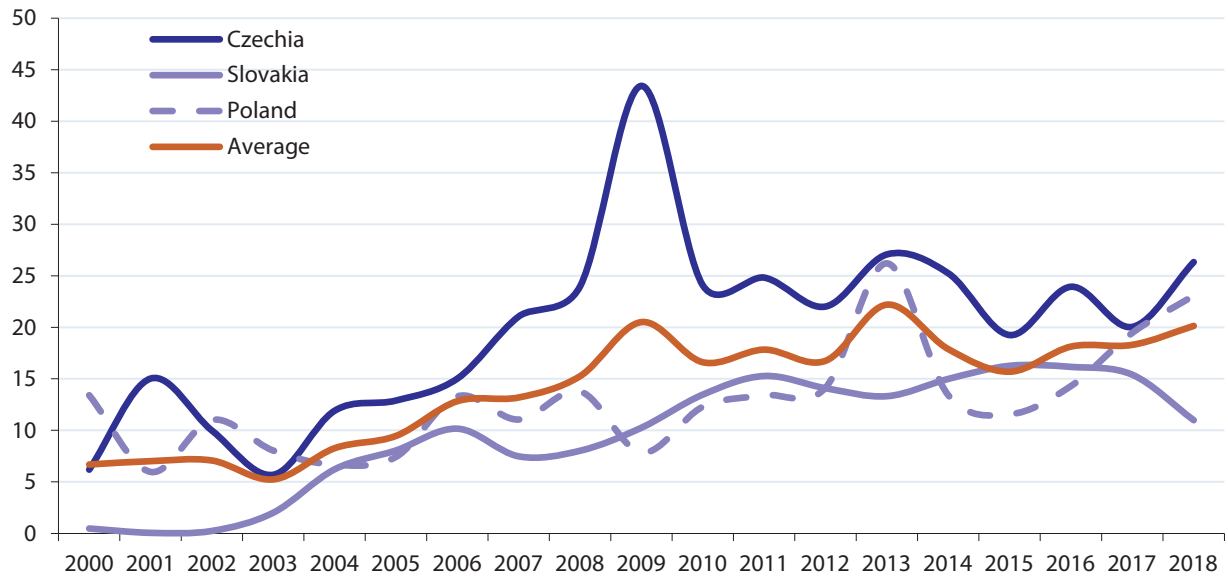

Fig. 4. *Betweenness centrality for the automotive production networks of EU peripheral economies (2000–2018). Source: authors' elaboration*

importance in the whole network as the connecting links (see Figure 4).

According to this metric, all three countries have become more important as the intermediaries in the network. Moreover, there is a strong evidence that betweenness centrality of three peripheral economies began to multiply straight after their entry into the Union in 2004. Currently, the most influential peripheral countries in the EU automotive production network, according to this metric, are Czechia and Poland, while Slovakia is weakly tied with member countries in the sector.

5. Discussion and Implication

Conceptually, our findings correspond with the general perception of the global production through the lenses of 'core-periphery' relations (Krugman, 1991; Wallerstein, 2011). According to Pavlinek (2021), our three peripheral economies can be categorised as unstable semi-periphery (Czechia), stable periphery (Poland) and unstable periphery (Slovakia) based on 'automotive industry power' capturing positional, ownership and control, and innovation powers. In that sense, our betweenness centrality metrics convincingly support such stratification. Importantly, a positive evolution of the transitivity coefficient and relative stability of reciprocity testifies to a solid foundation behind the European automotive sector, which resonates with what Frigant and Zumpe conclude (2014, p. 27).

Another important notion is that EU peripheral economies are all stagnating in terms of labour productivity in the sector (gross value-added / employment), while core-countries (such as Germany) demonstrate sustained growth (Gerőcs & Pinkasz, 2019). Our calculations of GVC indicators, at least for Czechia, suggest that these countries begin to favour preferable position in GVCs reaping additional gains.

All in all, two specific years — 2004 and 2008 — deserve particular attention. Namely, Czechia and Slovakia favoured an immediate positive effect of the entry into the EU, which is pictured by the betweenness centrality index, while Poland have also captured this opportunity, though with

a two-year lag. This result, in our opinion, contributes to the set of studies on economic development of Visegrad countries in recent decades (Vlčková, 2018; Kokocinska & Puziak, 2018). It is worth pointing out that 2004 related changes are not depicted in the GVC indicators figures. Regarding 2008, in our opinion, the analytical interconnection of GVC and network perception is crucial for determining the relative changes of the EU periphery participation in spatial automotive production.

6. Conclusions

In this paper we have attempted to theoretically and methodologically compare GVC and GPN approaches with a particular notion of GVC shortcomings (namely, linearity, lower geographical reliability and high level of aggregation).

In the first part of the article, we highlighted that 'spiders' and 'snakes' structures contradict with GVC perception of international production. Additionally, governance patterns lack validity without the account of network-specific advantages of local units. Finally, it was demonstrated that GPN approach intersects heavily with the general network theory which allows for the extrapolation of some assumptions (such as the resilience of different grid structures) to the study of spatial production systems.

In the second part of the paper, our conceptual findings were justified empirically by calculating the betweenness centrality, density, reciprocity and transitivity metrics of the EU automotive production network, and matching them with GVC participation indicators (such as domestic value-added in exports of intermediate products of a given industry).

First, network indicators identified the way 2008 crisis has influenced the sectoral development. The impact has been quantitative, rather than structural since, despite the increase of GVC forward participation of Poland and Slovakia, their relative cooperation pattern with other partners remained unchanged. Second, the 'slowbalisation' tendency has been unveiled. Namely, the density metric suggests a relative stagnation in forming new linkages between the nodes in the network after 2011. Third, the specialisation patterns of the three analysed peripheral economies have been clarified with an application of network-based indicators. Specifically, it has been shown that Czechia and Slovakia transit from cooperation in production of motor vehicles to cooperation in parts and equipment manufacturing.

Overall, our study appeals to a better interpretation of GVC and GPN methodological proposition so as to study international production in a more elaborate way. Moreover, regional patterns of cooperation in automotive sector as being referred to as 'core-periphery structures' cannot be properly characterised without the introduction of relational aspect.

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