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Exploring supply chain and regional resilience through the analysis of the transport dimension

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ABSTRACT

Despite the key role that global supply chains (GSC), and more specifically, the transport and logistics function, might play in the performance of regions, there is a lack of analytical tools that turn the data generated by supply chain operations into quantitative metrics allowing policymakers to identify early signals of potential vulnerabilities and assess how resilient the GSC are at regional level. In an effort to fill this gap, we present a Transportation Resilience Index (TRI) that permits evaluating how transport chains affect supply chain resilience and, consequently, regional resilience. Our index, based on publicly available data –statistics on foreign trade flows provided by the Spanish Customs, the World Bank' Logistics Performance Index and the UNCTAD' Bilateral Liner Shipping Connectivity Index – differentiates between the determinants over which the company has direct decision-making control, and those linked to the selection of the supply market (market and macro dimensions). The TRI is applied to the Spanish regions (NUTS2) by using the Benefit-of-the-Doubt (BoD) approach to Data Envelopment Analysis (DEA) and applying a Common Set of Weights (CSW) for the selection of the weights to the index components. In our specific analysis, the market and macroeconomic components account for 84% of the total weight of the TRI. Despite the lower relative weight of the company dimension, the high degree of homogeneity in the market and macroeconomic scores means the company dimension plays a key role in the relative resilience of the Spanish regions.

1. Introduction

It is widely believed that integration into global value chains (GVC) at regional and industry level leads to economic upgrading (Gereffi, 2019), especially for areas under development. So pervasive is this argument (Pahl and Timmer, 2020) that many countries and regions have heavily invested in GVC embeddedness in an effort to secure the benefits of production and process specialization (Humphrey and Schmitz, 2002). The term GVC refers to an international production model based on organizational systems that interconnect companies through a network of agreements (Gereffi, 1994; Giroud and Mirza, 2015). At the operative level, the focus is increasingly turning to global supply chains (GSC), since they are the channels through which the actors in GVC maintain their links, making the whole production system work. While the large number of stakeholders and interactions constitutes an added source of vulnerability, an increasing branch of operational research concentrates on developing tools strengthening interactions resilience (Hrušovský et al., 2022). Consequently, managing the supply chain improves the competitiveness of regions and industries as it reduces uncertainty in the network (Al-Mudimigh et al., 2004). Moreover, given the crucial role played by GVC and GSC on the economic performance of territories, both are key to achieve regional resilience.

Due to the importance of GSC in today's marketplace, in the last years, it has been at the centre of the economic debate drawing the attention of researchers, policymakers and international institutions

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(UNCTAD, 2021). The main reason is the recent poor performance of the system under the severe stress of recent years, especially during (but not limited to) the COVID pandemic, which has caused serious interruptions in many firms' activities (Pallás-Rocafull et al., 2023). Various difficulties (supply and demand shocks, port congestion, container shortages, lack of capacity, low schedule reliability, delivery delays and high shipping rates) interrupted normal delivery, causing serious problems in the performance of international firms (Notteboom et al., 2021; Gu et al., 2023). As highlighted during and after the pandemic, transport and logistics disruptions are potential sources of vulnerability in supply chains, affecting the exchange of physical flows of cargo between companies belonging to the GSC (Herold et al., 2021; Caballini et al., 2022). These disruptions can influence the productive structure of the regions participating in the GVC, which can have very negative consequences in terms of employment and economic activity (Chacon-Hurtado et al., 2020; Caramuta et al., 2023). Thus, given the complex and dynamic nature of GSC operations, regional policymakers require constant vigilance to identify the potential sources of regional resilience, and to assess the vulnerabilities of the supply chains in which their companies and territories are involved (Fröhlich and Hassink, 2018).

Therefore, in an effort to fill this gap, our research aims to develop an index to measure GSC resilience at regional level. More specifically, we focus on measuring the role of transportation as key determinant of Supply Chain Resilience (SCR) (Ponomarov and Holcomb, 2009). To the best of our knowledge, this is the first paper that study supply chain resilience as a determinant of regional resilience.

In this regard, recent literature calls for researchers to develop indicators to measure the current level of resilience, allowing users to anticipate problems from early signals of potential vulnerabilities (Zhang et al., 2015; Pettit et al., 2019). It is well-known the interest of companies, policymakers and international institutions in such tools (Blackhurst et al., 2011), so it is surprising how few academic studies address this relevant issue (Azevedo et al., 2016), especially in studying the relationship between regional resilience and SCR (Sabouhi et al., 2021).

We present a Transport Resilience Index (TRI) that differentiates between the determinants over which the company has direct decision-making control (the company component) and those linked to the selection of the supply market (the market and macro components).

The TRI allows policymakers and managers to identify the strategies for improvement that fall within the scope of the company and, conversely, those elements affecting the transport chain that are directly linked to the country of supply. The TRI is also useful for policymakers and managers to assess the resilience of their transport and supply chains, providing valuable information to help them design the most effective measures to increase their resilience, and subsequently verify whether their objectives have been achieved.

We illustrate the use of the TRI for the case of the imports of intermediate goods within GVCs across 17 Spanish regions (NUTS2 level) in 2019, using the Benefit-of-the-Doubt (BoD) approach to Data Envelopment Analysis (DEA) and applying a Common Set of Weights (CSW) for the selection of the weights to the index components. It is worth highlighting that finding the set of weights is considered a critical decision that can be extremely complex in terms of methodology. In this regard, the BoD-DEA-CSW approach used in this paper guarantees that the weights generated are unique and reach a Pareto-optimal solution.

In the case of the Spanish regions, our results show that macroeconomic and logistics performance of the supplier country are critical in the TRI and, therefore, the reshoring might be an effective strategy for regions seeking to improve their level of resilience. Moreover, at the company dimension, we identified that the use of low-control incoterms and, especially, the total concentration around road transport for supplies are penalising the resilience of some Spanish regions, giving policymakers plenty of room for improving their resilience.

This research addresses the critical need for robust indicators to monitor the resilience of global supply chains. Specifically, it aims to develop and indicator allowing policymakers and supply chain managers to effectively gauge the impact of transportation choices on overall supply chain resilience. The paper offers three main contributions: first, the study of supply chains as a determinant of regional resilience; second, the development of an index to evaluate the vulnerabilities and strengths in terms of transport that allows policymakers to develop the most effective measures to enhance resilience; third, an illustrative case of analysis using the index for assessing the resilience of logistics and transport chains linked to the supply of GVCs in the different Spanish regions.

The paper is structured as follows: after briefly reviewing the literature in Section 2, Section 3 presents the components and variables of the TRI and section 4 describes the weighting method employed. In section 5 we apply the composite indicator to the Spanish regions, highlighting the policy implications both for companies and policymakers that can be drawn from the results obtained in Section 6. Conclusions and futures lines of work are presented in Section 7.

2. Literature review

2.1. Supply chain resilience (SCR)

From an integrated perspective, SCR can be defined as the "*adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function*" (Ponamarov and Holcomb, 2009), thus reflecting the extent to which the supply chain can respond to and recover from an unexpected event (Han, Chang and Li, 2020).

In recent decades, SCR has been studied widely from both qualitative and quantitative perspectives (Hosseini et al., 2019). So far, most of the related literature has focused on identifying the main antecedents and drivers that determine SCR, highlighting several of these factors. The most important are collaboration, agility, visibility, management culture, flexibility and information sharing (Hosseini, Ivanov and Dolgui, 2019).

However, a surprising lack of attention is paid to the management of the transport and logistics chains as a pillar of supply chain management, with its potential for strengthening SCR remaining underexploited (Pettit, Croxton and Fiksel, 2019). In this regard, transport plays a key role for firms to reduce delivery times, increase reliability and flexibility in their shipments and, it is a key determinant of the spatial configuration of value activities (Higgins et al., 2023). Despite of this, there is scarce empirical evidence on the role of transportation and logistics in enhancing SCR (Mandal et al., 2017). In addition, most of the proposed indicators focus on specific case studies mainly related to maritime supply chains and ports as their key node (León-Mateos et al., 2021; Jiang et al., 2021; Calatayud et al., 2017; Lam and Bai, 2016). To the best of our knowledge, there are even fewer holistic approaches aimed at measuring the resilience of international transport and logistics chains, although an increase in published research on the subject can be observed in recent years (see for example Cedillo-Campos et al., 2022; Schofer et al., 2022; Jomthanachai et al., 2021; Jiand and Scarffe, 2021; Vanlaer et al., 2022).

2.2. Regional resilience

Among the several possible definitions of term resilience in the literature, a resilient region can be considered one that retains the capacity to recover from external shock (Christopherson et al., 2010). Thus, regional resilience is a multidimensional concept that can be studied using different approaches (Fröhlich and Hassink, 2018): urban ecology and policies; economic dynamics and regional evolutionary perspectives; and crisis management and modelling.

In our particular case, our emphasis lies on crisis management. To date, the predominant body of literature has concentrated on examining how regions manage crises, particularly in response to economic and financial disruptions, and the strategies employed to restore equilibrium (Christopherson et al., 2010; Capello et al., 2015; Giannakis and Bruggeman, 2017a; Giannakis and Bruggeman, 2017b; Sensier et al., 2023). However, other type of business and production disruptions affecting regional resilience have been largely overlooked and very few researchers have attempted to study it. In this regard, the impact of the supply chain on regions' performance remains an under-researched subject in the literature (Sabouhi et al., 2021). In fact, GSCs serve as the channels through which actors engage at the operational level within GVC. Consequently, the effects of potential disruptions within this system on the economic activities of regions hold significant relevance.

Furthermore, a limited number of papers have explored the development of analytical tools designed to enable policymakers to assess the strengths and weaknesses of regions. These indexes aim to evaluate the regions' readiness to confront the challenges and ramifications associated with potential disruptions. Although there are some papers aiming to develop such indicators from an economic perspective (Sensier et al., 2023), the majority of existing literature explore the recovery of regions affected by natural disasters (Fröhlich and Hassink, 2018).

3. The transport resilience index: Definition and variables

Our index focuses on the inbound flow from the perspective of an importer (Figure 1), taking the companies' international sourcing strategy as given. In this way, once the importing company has selected the supplier for its products (the decision is treated as exogenous to the model in our case) and its corresponding supply chain has been established, the resilience of its transport is evaluated by the TRI. The country where the supplier is located, while directly determined by the companies' sourcing strategies, is crucial since it determines the availability and quality of transport services and the resilience of the country in terms of its logistics, infrastructure, and economy.

The index includes indicators of key elements that characterize the relationship between importer and supplier linked to the physical flow of goods and their transportation service. These variables are grouped into three dimensions—company, market and macroeconomic—established according to whether the importing company can directly affect said elements and thereby modulate its level of exposure to potential disruptions/risks to the transport chain (Figure 2).

The indicators that make up the company dimension of the TRI are based on the statistics on foreign trade flows provided by the Customs, while those comprising the market dimension are indexes provided by the World Bank (the Logistics Performance Index) and by UNCTAD (the Bilateral Liner Shipping Connectivity Index). The characteristics and contents of these databases are summarised in Table A.1 and the descriptive statistics of the variables included in the index are presented in Table A.2 in Appendix 1. The specific variables and their different sources used for the macroeconomic dimension are detailed in Appendix 2.

The unit of analysis is the value of imports and all the indicators are calculated at the 6-digit code level of the Harmonized System (HS) nomenclature of the World Customs Organization.

3.1. Company dimension

The *company dimension* groups together the elements that can affect the resilience of the transport and logistics chain and that the company has direct decision-making control over. The company dimension consists of the following three indicators:

Control over the transport chain: This variable has been measured by the share of imports covered by Incoterms in groups E and F in total imports (groups in which the importer is mostly responsible for transport management). Incoterm rules reflect business-to-business practices in contracts addressing the tasks, costs, and risks involved in the physical delivery of goods from sellers to buyers (Coetzee, 2013). From the inbound flow perspective, the buyer's obligations are the greatest in EXW and Group F Incoterms, and they gradually lessen in Groups C and D (Stojanović and Ivetić, 2020).Incoterm rules usually require many important decisions, such as subcontracting in logistics involving one or both sales contract sides, which in some cases can lead to complex logistics networking that influences the performance of international delivery and thus of the supply chain (Stojanović and Ivetić, 2020). Under group E and F Incoterms, if any disturbance occurred along the supply chain, the importer would have the necessary control over the transport chain to make decisions and rapidly respond. Consequently, the resilience of the supply chain will be greater when importing companies use Incoterms in groups E and F.

Intermodality: this indicator reflects the degree of diversification of sectoral transport chains in terms of the modes of transport used (Niérat, 2022). Following Azebedo et al., (2013) and Jiang and Scarffe, (2021), we expect that the greater the diversification of the modal split, the lower the risks associated with disruptions in a given mode and the higher the resilience of the supply chain.

The Herfindahl-Hirschman Index (HHI) has been used to capture intermodality. It has been calculated taking as a reference a maximum of five modes of transport: road, air, maritime, rail and "others". This last category includes the rest of the modes reported in the statistics, which represent a negligible share of Spanish foreign trade: self-propulsion, fixed platform, postal traffic, inland waterway transport and unknown. The formula is:

$$HHI = \sum_{i=1}^{n} S_i^2 \tag{1}$$

where i denotes the mode of transport, n the total number of available modes and S_i the market share of mode i.

Since the number of available modes varies according to the market of origin, the HHI has first been calculated at product and country level and then aggregated at product level by weighting product/country HHIs by the share of imports from these countries in total imports of the product.

Value: this variable captures the relative value of the shipment (€ per kg) through its unit value index (UVI, the ratio of value to weight). High UVIs reduce the share of transportation costs in total costs, thus allowing companies to shift to more expensive transport chains but with higher levels of service.

3.2. Market dimension

In the *market dimension* we find components that affect the resilience of the transport chain but whose configuration is beyond the control of companies since their levels directly depend on the decision to source from one country or another. The supplier country has important implications in terms of the number of transport modes available, the length of the supply chain, the degree of integration into the international transport network and the quality of logistics services and infrastructures. In this regard, Calatayud et al. (2017) found that the vulnerability of the supply chain varies according to the pairs of country of origin and destination analysed; therefore, the market dimension has a strong effect on SCR. The market dimension consists of the following three indicators:

Logistics performance: Empirical evidence to date has demonstrated the importance of logistics and transport infrastructure

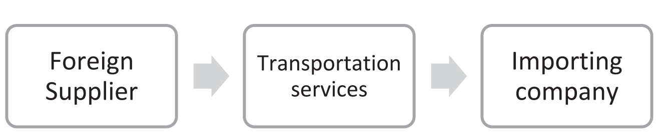


Fig. 1. Inbound flow under study.

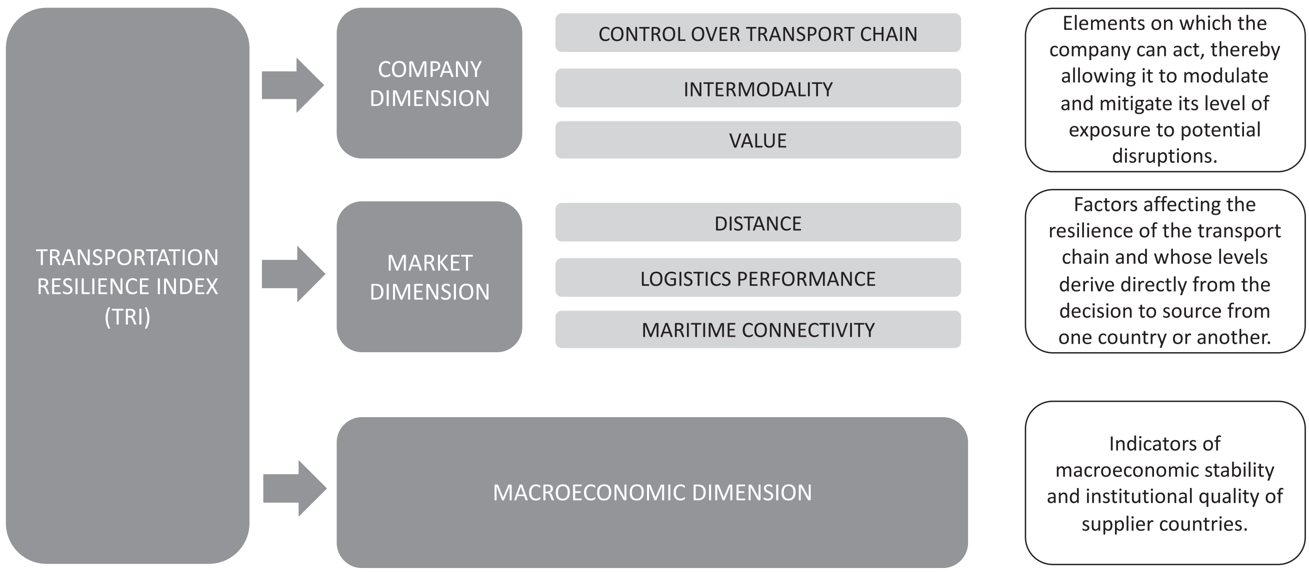


Fig. 2. The TRI, its dimensions and components.

performance for facilitating trade flows and reducing transport cost (Martí et al., 2014; Rokicki and Stępniak, 2018). Indeed, infrastructure that is lacking or inadequate is considered one of the main barriers preventing companies located in emerging countries from successfully participating in GVC (Cedillo-Campos et al., 2016).

The quality of logistics infrastructure and service in the supplier countries is measured through the score obtained in the World Bank's Logistic Performance Index (LPI) (Arvis et al., 2014) weighted by the share of imports from each country of origin in the total imports of the product at the 6-digit code level of the Harmonized System nomenclature. The international LPI is an overall measure of the efficiency of the logistics sector, combining data on six key performance indicators—customs, infrastructure, ease of arranging shipments, quality of logistics services, tracking and tracing, and timeliness—into a single aggregated measure (Beysenbaev and Dus, 2020).

Maritime connectivity: This variable is crucial for exporting and importing companies since more than 80 % of freight trade is transported by sea (UNCTAD, 2020). The empirical evidence reveals that maritime connectivity has a positive effect in terms of reducing transport costs (Wilmsmeier et al., 2006) and enables the integration of countries into the international transport network (Mohamed-Chérif and Ducruet, 2016). Since industries integrated into GSC are increasingly dependent on shipping services (Lam, 2011), the level of bilateral maritime connectivity between each pair of countries has a direct effect on reliability, timeliness and flexibility for companies in managing their shipments (Martínez-Moya and Feo-Valero, 2020; Liu et al., 2022). Thus, the higher the level of maritime connectivity, the more resilient the supply chain. Maritime connectivity between Spain and its supplying countries has been measured here through the score obtained in the Bilateral Liner Shipping Connectivity Index produced by UNCTAD (Unctad, 2014).

Distance: The distance between a pair of countries has a direct effect on the potential disruptions that may occur during the transportation of the goods. Large distances between suppliers and final markets of production and consumption generate uncertainty in supply continuity due to longer and more variable lead times (Colicchia et al., 2010). Moreover, long-distance sourcing may cause communication and information flow problems, making it difficult to establish a more collaborative relationship with suppliers, causing further delays and shortages (Tukamuhabwa et al., 2017). Therefore, the greater the distance, the longer the transit time of the transport chain and the lower the probability of having a direct transport service, meaning a higher likelihood of suffering delays. In our index, distance is measured as the geodesic distance between Madrid and the capital of the supplying country weighted by the share of imports from each country of origin in the total imports of the HS6 product.

3.3. Macroeconomic dimension

Finally, the *macroeconomic dimension* allows us to complement the two previous components with indicators of the macroeconomic stability of the countries of origin of the imports. In addition to having a direct impact on the risk associated with sourcing from one market or another, this stability might also condition the quality and reliability of its logistics services. The relevance of macroeconomic and institutional factors must be considered when analysing the resilience of current value chains. The stability of the economic, legal, and institutional framework of the key countries for a particular chain may be of critical importance for maintaining (or changing) the way a firm gets its imported goods.

The macroeconomic dimension itself is a composite index, consisting of four different pillars capturing the countries' economic stability (inflation and exchange rate volatility), productive efficiency (total factor productivity, labour productivity), institutional quality (corruption, governmental efficiency, and economic freedom) and resources and costs (labour costs, physical and human capital). Figure 3 shows the variables included in the macroeconomic dimension. The macroeconomic dimension is measured as a global score, from 1 to 5, for every pair country-year, where 1 (5) is the best (worst) value, meaning the highest (lowest) degree of resilience added to the value chain by the macroeconomic framework, and entering into that chain through the suppliers operating in a particular country in a specific year. The global score is calculated as the average of the score for each of the four pillars, under the assumption of equal weights. In turn, the variables considered for each pillar are individually assigned a value of 1 to 5 and equally weighted, resulting in the score for the corresponding pillar.

4. Methodology

In the construction of composite indicators, deciding what weight to assign to each variable is critical as it potentially affects the accuracy of the measure. The challenge is to find the set of weights that allows the researcher to identify the relevance of the variables for measuring transport chain resilience (Mishra et al., 2021).

To address this challenge, we construct our composite indicator

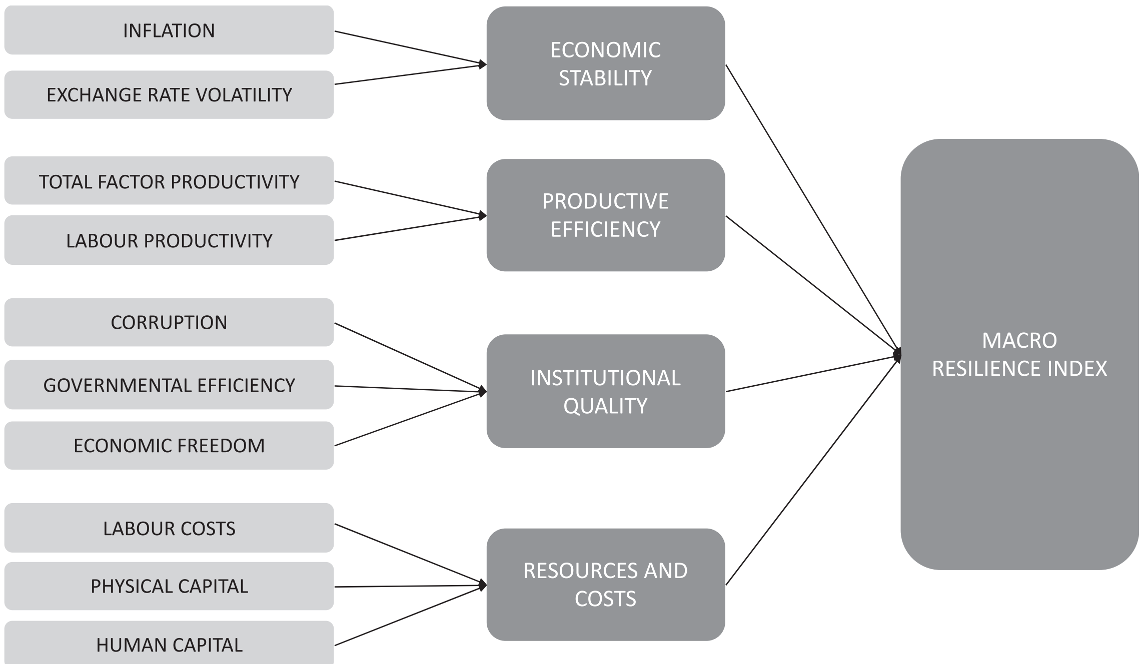


Fig. 3. Variables comprising the macroeconomic dimension.

using the Benefit-of-the-Doubt (BoD) approach to Data Envelopment Analysis (DEA) and applying a Common Set of Weights (CSW) for the objective selection of the weighting scheme—that is, we implement a BoD–DEA–CSW approach (Martinez-Moya et al., 2023). DEA has been applied to the construction of composite indicators because it can be used to assign weights to each variable and aggregate them into a single composite indicator (Savić and Martić, 2017).

In a first stage, we estimate the BoD-type DEA model, which allows an objective selection of the weights (Charnes et al., 1978; Cherchye et al., 2007). To this end, the following BoD-DEA model was estimated:

$$\begin{gathered} Max\, h_j = \sum\nolimits_{j=1}^{m} w_j y_{kj} \\ \text{s.a.} \\ \sum\nolimits_{j=1}^{m} w_j y_{kj} \leq 1\, \forall k = 1, 2, \cdots, K \\ w_j \geq 0\, \forall j = 1, 2, \cdots, J \end{gathered} \tag{2}$$

where w_j denotes the weight assigned to each of the Decision-Making Units (DMUs) (j) using the outputs or values assigned to each of the indicators (K) for each DMU, and y_{kj} take values ranging between 0 and 1.

However, with this type of BoD-DEA model, each DMU is evaluated according to its optimal weighting scheme. This is a disadvantage for comparative analyses, since it is unfair that the same component is assigned different weights in the evaluation of different DMUs (Contreras, 2020).

To overcome this drawback, in a second stage, the DEA model can be estimated under CSW (Cook and Kress, 1990; Wu et al., 2016) to obtain a common base for the evaluation of all the DMUs. In doing so, all DMUs are evaluated using the same weighting profile, which allows the comparison of their individual scores.

We use the CSW method proposed by Wu et al. (2016) since this approach involves a max–min model and two algorithms for assigning the common weights. Firstly, the max–min model accompanied by algorithm 1 can generate an equal set of weights for all DMUs. However, the solution may not be unique, meaning there may be several alternative solutions. Secondly, algorithm 2 is used to guarantee that the CSW generated is unique and reaches a Pareto-optimal solution. All these factors help ensure the evaluation provides satisfactory results for all DMUs and allow for better discrimination than traditional DEA models.

When using the CSW, each DMU has its own upper and lower efficiency target. On the one hand, the upper efficiency target E_j^{max} for a DMU is its Constant Returns to Scale efficiency when its optimal weights are selected. On the other hand, the lowest efficiency E_j^{min} of a DMU is reached when it is forced to use a set of weights that is the most favourable for another DMU and the least favourable for the DMU in question.

Finally, the CSW is formulated as a single-objective problem in model (2):

$$\max_{\mu,\varpi} \Phi$$

s.t:

$$\sum_{r=1}^{s} \mu_r y_{rj} - E_j^{max} * \sum_{i=1}^{m} \varpi_i x_{ij} + s_j^1 = 0$$

$$\sum_{r=1}^{s} \mu_r y_{rj} - E_j^{min} * \sum_{i=1}^{m} \varpi_i x_{ij} - s_j^2 = 0$$

$$\sum_{i=1}^{m} \varpi_i \sum_{j=1}^{n} x_{ij} = n$$

$$\frac{s_j^2}{s_j^1 + s_j^2} \geq \Phi$$

$$\varpi_i \geq 0 \forall i$$

$$\mu_r \geq 0 \forall i$$

$$s_j^1 \geq 0 \forall i$$

$$s_j^2 \geq 0 \forall i \tag{2}$$

where Φ denotes the objective function to maximise the satisfaction degree; μ_r and ϖ_i are the weights assigned to the outputs and inputs, respectively; y_{rj} and x_{ij} are the outputs and inputs of the DMU_j included in the model, respectively; E_j^{max} and E_j^{min} are the maximum and minimum score obtained by each DMU_j, respectively; s_j^1 denotes the slack of the first constraint of the maximum score; s_j^2 is the slack of the second constraint of the minimum score; n is the total number of DMU.

When the single-objective problem is solved, it is possible to generate the CSW, though it does not guarantee a unique solution for said weights. For this reason, the second algorithm is used to reach Pareto-optimal solution (Wu et al., 2016). Further details about the mathematical development of the second algorithm are provided in Wu et al. (2016).

5. An application of the tri to the case of spanish regions

In this section, we present a case study involving the application of the TRI to the imports to the 17 Spanish regions (NUTS2) within the framework of GVC in 2019. The analysis is limited to imports from the 55 countries for which the macro component has been calculated, which accounted for a 97.5 % share of the total imports of this type of product in 2019. More specifically, we analyse imports of products classified as *specific – processed – intermediate consumption – goods* in the fifth review of the Classification by Broad Economic Categories (UN, 2018). The specification dimension –distinguishing between generic and specific goods- was specifically introduced in the fifth review of the BEC classification with the objective of better identifying GVC related trade. While goods included in the *generic processed intermediate consumption* category have a wider applicability across industries and are therefore more indicative of arm's-length transactions underpinning more traditional trade, those classified as *specific processed intermediate consumption goods* correspond to explicitly coordinated trade characterising GVC.

Figure 4 shows the importance of GVC imports relative to both total Spanish GVC imports and in the regions' total imports. Almost half of Spanish imports linked to GVC flows go to just two regions (Cataluña and Madrid with 28.7 % and 22.5 %, respectively). However, other regions have a much lower share, it should be noted that the imports carried out within GVC are especially relevant in regions with less economic weight (relative to the total), such as Navarra or Castilla León. For instance, those two regions account for 3.67 % and the 7.09 % of the country's total GVC imports, respectively, but the imports associated with GVC represented 59 % and 51 %, respectively, of their region's total imports, evidencing the key role of GVC in the economic structure of Navarra and Castilla León.

Figure 5 shows the weights assigned to each component (company, market and macroeconomic) and within each component, using the BoD-DEA-CSW approach. This procedure allows us to perform an analysis of the overall resilience of the transport chain in a region together with an evaluation of the relative contribution of each component. It is thus possible to carry out both a global and a disaggregated analysis that allows us to assess the resilience of the transport chain and identify the variables where it can be improved.

The market (25.53 %) and macroeconomic (58.45 %) components, which are directly linked to the choice of supplier country, account for 84 % of the total weight of the TRI. This clearly shows the importance of this critical decision for companies seeking to improve their level of resilience. Although in this study, the selection of the supply country is

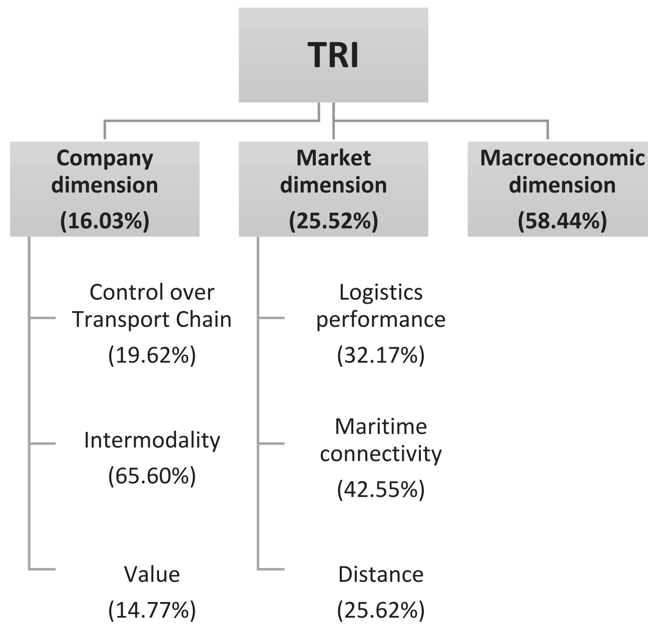
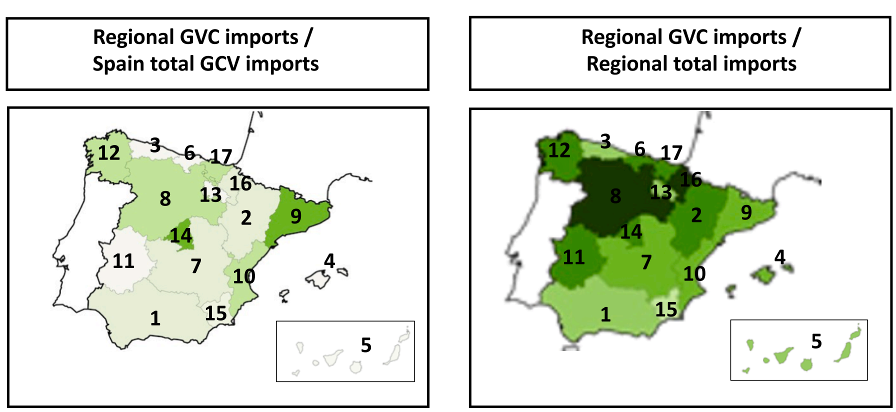


Fig. 5. Weights assigned to each component.



1. ANDALUCÍA	4,86%	10. C. VALENCIANA	8,30%
2. ARAGÓN	4,20%	11. EXTREMADURA	0,58%
3. ASTURIAS	0,62%	12. GALICIA	6,90%
4. BALEARES	0,34%	13. LA RIOJA	0,30%
5. CANARIAS	0,62%	14. MADRID	22,47%
6. CANTABRIA	0,78%	15. MURCIA	0,97%
7. CASTILLA LA MANCHA	2,82%	16. NAVARRA	3,67%
8. CASTILLA LEÓN	7,09%	17. PAÍS VASCO	6,80%
9. CATALUÑA	28,69%	TOTAL SPAIN	100,00%

1. ANDALUCÍA	15,45%	10. C. VALENCIANA	26,79%
2. ARAGÓN	32,60%	11. EXTREMADURA	35,64%
3. ASTURIAS	14,70%	12. GALICIA	34,79%
4. BALEARES	20,20%	13. LA RIOJA	19,56%
5. CANARIAS	16,19%	14. MADRID	31,62%
6. CANTABRIA	32,01%	15. MURCIA	8,98%
7. CASTILLA LA MANCHA	26,63%	16. NAVARRA	59,03%
8. CASTILLA LEÓN	51,29%	17. PAÍS VASCO	31,96%
9. CATALUÑA	29,21%	TOTAL SPAIN	29,20%

Fig. 4. The share of GVC imports in total Spanish GVC imports (left side) and in the regions' total imports (right side).

considered exogenous, switching the sourcing country (and with it the level of resilience associated with the market and macroeconomic components) is a plausible scenario in the mid and long term. In this sense, the regionalization of supply chain networks and reshoring strategies are a reflection of firms reconsidering their sourcing decision. Recently, these strategies have been presented as a way of gaining control over the supply chain (Kano, Narula and Surdu, 2022).

Table 1 shows the values calculated for the total TRI and for each of its three components, based on the weights derived from the CSW. Values are defined in the interval [0,1], with the value 1 corresponding to the Spanish region with the best score, the benchmark against which the scores of the remaining regions are determined.

The results obtained show a high degree of homogeneity in the market and macroeconomic scores used to determine the relative resilience of the Spanish regions. This homogeneity in the two scores is explained by the “EU effect”: the majority of import flows come from EU partners. The share of import flows from EU countries ranges from a minimum of 50 % (Andalucía) to a maximum of 87 % (Extremadura), with the average for Spain being 68 %. To be more exact, there is a high concentration around a few countries, especially Germany, France and Italy. Germany plays a central role since it is the main supplier of 12 of the 17 Spanish regions under study (in the 5 remaining regions it is the 2nd or 3rd most important supplier), and accounts for 19.74 % of total Spanish import flows of intermediate products associated with GVC activities. France and Italy are similarly important suppliers, with both positioned in the top 5 of 17 Spanish regions. In terms of non-EU suppliers, the role of China deserves special attention, as it accounts for 14.4 % of import flows of intermediate products associated with GVC activities, being among the top 5 suppliers in 10 out of the 17 Spanish regions.The high concentration of supplies around these countries explains why the level obtained for the market and macroeconomic components is found in all cases to be very close to the level displayed by the top performing region.

Despite the lower relative weight of the company dimension in the TRI (accounting for 16 % of the total weight), the high degree of homogeneity in the market and macroeconomic scores means the company dimension plays a key role in the relative resilience of the Spanish regions. The regional differences in terms of the proposed composite indicator are therefore determined by those factors under the control of the firm. Thus, Extremadura, which leads the ranking in the market and macroeconomic components, is relegated to 11th position in the ranking based on the TRI due to its large negative differential in terms of the company component. On the contrary, Madrid, which is in 8th and 11th position for the market and macroeconomic component, respectively, is 2nd in the TRI ranking thanks to its strong relative performance in the company dimension.

6. Discussion and policy implications

After analysing the results, it is worth highlighting the policy implications both for companies and policymakers that can be drawn from the results obtained for the TRI and its components.

On the one hand, given the weight assigned to the macro and market components of our index, the selection of the supplier (and, implicitly, the country where it is located) is a critical decision for managing the location or restructuring the activities along the value chain. Hence, strategies focused on modifying the supply chain concerning its length and the geographical dispersion of value have assumed a prominent position in recent years within the academic discourse. Notably, the concept of reshoring has emerged as a noteworthy strategy, characterized by the repositioning of productive activities to the domestic country or a nearby geographical vicinity, which were previously internationalized (Barbieri et al., 2017). Given that reshoring frequently entails foreign direct investment initiatives and the reversal of substantial prior investments, it is typically regarded as a medium to long-term strategy. The feasibility of implementing this strategy is more pronounced in sectors where automation and substantial capital investments exert substantial influence, where proximity to customers and the corporate reputation, rather than wage costs, dictate competitiveness (e.g., machinery and equipment, electronics, automotive). In this context, when reshoring is considered a feasible option for strategic sectors in terms of regional production and employment, policymakers may generate incentives and formulate requisite policies to facilitate such relocalization endeavors. In this regard, France, Japan, Singapore, Australia and India are only some examples of countries fostering initiatives to stimulate the relocation of critical sectors and supply chains through policies aiming to reduce the economic cost of reshoring these activities (Barbieri et al., 2020).

On the other hand, at company level, the results of the Index show a high degree of heterogeneity between regions in terms of the company components. The elements that make up the company dimension are of special interest, both because in the short term they are the only ones over which the company has direct decision-making control, and because of their decisive effect on the TRI ranking. The information shown in Figures 6 and 7 about the scores obtained by each Spanish region for the *control over the transport chain* and *intermodality* indicators respectively, allows us to delve into the performance of the regions in terms of these factors. Bubbles are sized according to the weight of the

Table 1
Results of the TRI and disaggregated by its components.

	TRI		COMPANY		MARKET		MACRO	
	VALUE	POS/RANK	VALUE	POS/RANK	VALUE	POS/RANK	VALUE	POS/RANK
ARAGÓN	1.000	1	1.000	1	0.953	13	0.999	2
MADRID	0.986	2	1.000	2	0.969	8	0.956	11
NAVARRA	0.963	3	0.800	5	0.978	7	0.995	4
GALICIA	0.962	4	0.862	3	0.997	4	0.948	14
C. VALENCIANA	0.939	5	0.816	4	0.943	16	0.962	9
CATALUÑA	0.938	6	0.728	7	0.961	11	0.988	6
CAST. LA MANCHA	0.929	7	0.746	6	0.989	6	0.938	15
MURCIA	0.906	8	0.585	9	0.955	12	0.991	5
CANTABRIA	0.904	9	0.616	8	0.949	15	0.976	7
PAÍS VASCO	0.896	10	0.520	15	0.962	10	0.996	3
EXTREMADURA	0.888	11	0.413	17	1.000	1	1.000	1
CASTILLA LEÓN	0.885	12	0.505	16	1.000	2	0.948	13
ASTURIAS	0.882	13	0.539	13	0.950	14	0.965	8
LA RIOJA	0.881	14	0.536	14	0.964	9	0.952	12
BALEARES	0.875	15	0.572	11	0.998	3	0.895	17
CANARIAS	0.873	16	0.541	12	0.995	5	0.908	16
ANDALUCÍA	0.873	17	0.580	10	0.909	17	0.956	10
TOTAL SPAIN	**0.942**		**0.775**		**0.966**		**0.970**	

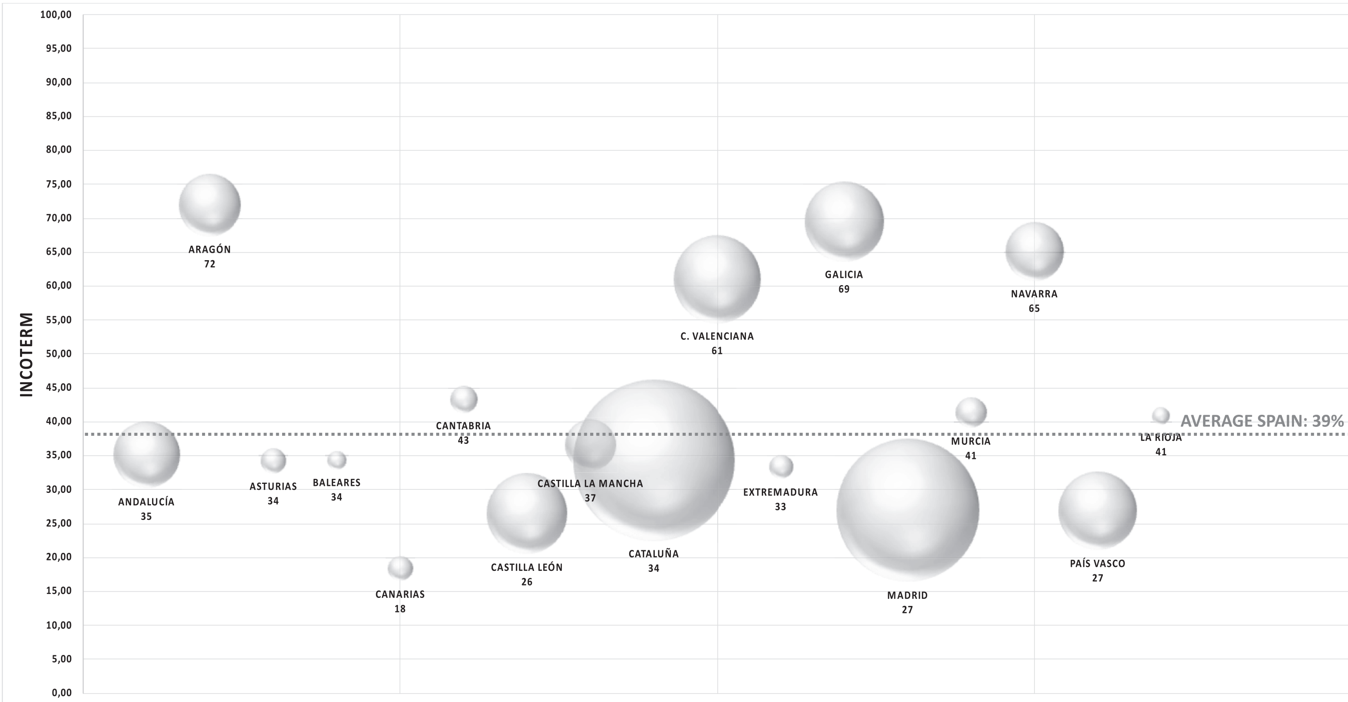


Fig. 6. The relative position of Spanish regions with respect to their average score in Incoterms.

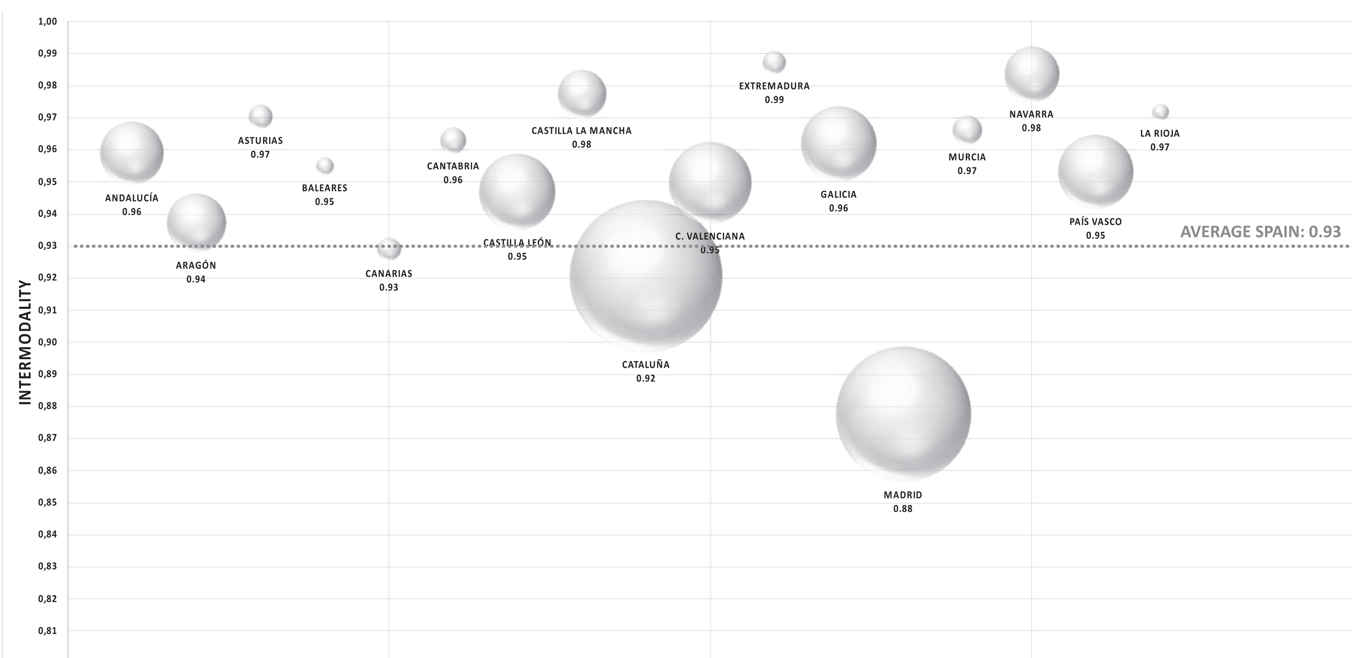


Fig. 7. The relative position of Spanish regions with respect to their average score in intermodality.

regions' GVC imports relative to total Spanish GVC imports.

The *control over the transport chain* indicator ranges between 0 and 100, with higher values signifying greater resilience. As can be seen (Figure 6), there is plenty of room for improving resilience through the Incoterm, since the average share of imports covered by the Incoterms in groups E or F is only 39 % for the whole of Spain. This result is consistent with the relative logistical immaturity of Spanish companies, who have historically tended to opt for low-control Incoterms. Generally, the Incoterm used in each shipment depends on the bargaining power between exporting and importing companies. Therefore, the size of the company is a relevant factor that determines such negotiation power. In the case of the Spanish productive structure, this is characterised by the dominance of small and medium companies, who sometimes have more limited bargaining position. This trend would be reflected in the flows analysed since, except in the case of Aragon, Galicia, Navarra and the Valencian Community –whose productive structure is characterised by the presence of multinationals from automotive industry, for which the use of high-control Incoterms is the standard-, there still relatively few GVC supplies in which the Spanish importer assumes control of the transport chain. In this regard, the role of industry associations and other institutions becomes crucial to disseminate the advantages of using high-control Incoterms and provide operational training to companies.

In terms of intermodality (Figure 7), most of the import flows associated with GVC come from EU countries, where there are four modes of effective transport alternatives to choose from (air, sea, rail and road). In this regard, the high concentration of all the regions is striking, with all the Spanish regions registering scores very close to the maximum value of 1. This is indicative of the total concentration around a single mode of transport for supplies, i.e., road. Therefore, there is also space here for improving resilience by using alternative intermodal modes, which, besides making their transport chains more flexible and resilient, would have a positive impact on the sustainability of the transport system (since road transport, which is the mode most used in intra-European trade flows, is the one that generates the highest negative externalities). Thus, the role of policymakers is deemed essential to develop the most effective economic measures to incentive the use of intermodal modes. In the case of Spain, in addition, given its peripheral geographical position in Europe, intermodality becomes crucial for the competitiveness of exporting and importing companies (Vázquez Paja et al., 2017). Potential measures to promote intermodal transport can be classified into two main groups depending on whether they act on the supply or demand side. In relation to the former, it is worth mentioning those aimed at developing infrastructure transport projects improving the accessibility of territories to intermodal modes of transport (López et al., 2008; Naranjo Gómez et al., 2022). In this regard, rail has historically been considered by policymakers as the main alternative to road transport (González-González and Nogués, 2016), concentrating a large part of the public sector's investment efforts in transport infrastructure. In the case of Spain, despite the efforts made, the rail share in freight transport remains, however, very residual (Vázquez Paja et al., 2017). In order to be fully effective, actions on infrastructure supply must be accompanied with measures aimed at adjusting both the quantity and quality of intermodal transport services being offered to demand requirements. Initiatives such as the railway liberalization for freight transport (which did not occur in Spain until 2007) or the Motorways of the Sea (European Commission, 2017) in the case of maritime services fall within this line of action. Demand-side policy actions of the second group seek to act mostly on a key determinant of modal choice, price (Feo-Valero et al., 2011). The eco-incentive initiative launched in 2022 by the Spanish government, which subsidises demand by granting aid to road hauliers who load their trucks or semi-trailers on short-sea shipping services, is a clear example of this type of action.

Therefore, policymakers have at their disposal different measures to be implemented depending on the element of the supply chain on which they aim to act (company or supplier) and the time horizon for action (short, medium y long term).

7. Conclusions

The major relevance of GVC for both international production and trade has made SCR a top priority for regional governments and businesses. Therefore, in this paper, we have built an index that evaluates the supply chain resilience at regional level through the analysis of the transport activities in relation to different dimensions (company, market and macroeconomics). Our Transport Resilience Index (TRI) is applied to the case of the Spanish regions' (NUTS2) imports of specific processed intermediate consumption goods in 2019. We believe that the TRI is a useful instrument to test the resilience of a real (or a potential) supply chain and region, taking into account the main determinants of that resilience.

Since the weight assigned to each variable is a critical decision in the construction of any composite indicator, we construct ours by using the Benefit-of-the-Doubt (BoD) approach to Data Envelopment Analysis (DEA) and applying a Common Set of Weights (CSW) for the objective selection of the weighting scheme. This procedure guarantees that the weights generated are unique and reach a Pareto-optimal solution.

In our specific analysis, the market and macroeconomic components account for 84 % of the total weight of the TRI, which shows the importance of the decisions about the country of origin of a firḿs suppliers if it wants to improve its level of resilience. Even if we take the source of the imports as given, our approach can still be used to analyse different options before the company selects its providers. For the Spanish regions, the TRI values show a high degree of homogeneity and a high level of resilience for those two dimensions, which can mainly be explained by the key role played by EU suppliers.

On the other hand, the company dimension in the TRI (even though it only accounts for 16 % of the total weight) shows far more heterogeneity among Spanish regions and offers more potential for improvement. This implies that the variables in the TRI that are under firms' control, such as the Incoterm, intermodality and UVI, will be crucial for boosting the resilience of the Spanish regionś supply chains.

In this paper, we prioritized the use of publicly available data to offer a user-friendly composite indicator. This probably entails some limitations regarding the type and scope of the data used. However, we believe that the TRI is a useful instrument to test the resilience of a real (or a potential) supply chain, taking into account the main determinants of that resilience. Additionally, the regional approach we applied here can be further developed by complementing it with both sectoral and temporal dimensions. Although the data employed refer to Spanish trade flows, the analysis of the potential presented by the databases of other countries trade flows represents an interesting extension of the work started here. To the extent that the data availability allows it, a comparison of the resilience of the GVC transport chains managed by different countries/regions through the proposed TRI and an assessment of its relative positioning in terms of its different components, would allow interesting conclusions to be drawn from a wider perspective.

CRediT authorship contribution statement

María Feo-Valero: Conceptualization, Data curation, Formal analysis, Funding acquisition, Writing – original draft. **Ana Botella-Andreu:** Conceptualization, Data curation, Supervision, Writing – original draft, Writing – review & editing. **Julián Martínez-Moya:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Funding acquisition. **Vicente J. Pallardó-López:** Conceptualization, Data curation, Funding acquisition, Supervision, Writing – original draft. **Francisco Requena-Silvente:** Data curation, Formal analysis, Supervision, Writing – original draft. **Ramón Sala-Garrido:** Formal analysis, Methodology, Supervision.

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Appendix 1 Databases used for company and market dimensions – TRI indicators

Table A.1.

	STATISTICS ON SPANISH FOREIGN TRADE	INT^{L} LOGISTICS PERFORMANCE INDEX (LPI)	BILATERAL LINER SHIPPING CONNECTIVITY INDEX (BLSC)
AGENCY	Tax Agency (Spain)	World Bank	UNCTAD
FIELD/SCOPE	Spanish foreign trade flows	Logistics performance; 160 countries.	Overall quality of a liner shipping connection between two countries; 138 countries.
PERIOD	• Frequency → monthly • Available period → since 1995	• Time unit → biannual • Available period → 2007, 2010, 2012, 2014, 2016, 2018	• Time unit → quarter • Available period → since 2006
SOURCE OF THE DATA	Statistics compiled from the data sourced from the Single Administrative Documents (SAD) linked to Spanish export/import operations with countries not belonging to the EU customs territory and from the INTRASTAT documents linked to introductions/dispatches with EU customs territory countries.	*Index constructed based on a worldwide survey of logistics operators providing quantitative and qualitative information on the logistics "friendliness" of the countries in which they operate and those with which they trade.*	Index constructed based on shipping schedules collected by MDS Transmodal
VARIABLES	• Month / Year • Flow (export/import) • Unit of measurement (weight / value) • Product (Combined nomenclature) • Country (origin/destination) • Spanish province (origin/destination) • INCOTERMS • Mode of transport	Index based on 6 dimensions: • Customs • Infrastructure • Ease of arranging shipments • Quality of logistics services • Tracking and tracing • Timeliness	Index based on 5 indicators: • N° of transhipments required • N° of common direct connections • Geometric mean of the n° of direct connections • N° of companies on the thinnest route • Size of the largest ships on the weakest route
WEB	https://sede.agenciatributaria.gob.es/Sede/estadisticas/estadisticas-comercio-exterior.html	https://lpi.worldbank.org/	https://unctadstat.unctad.org/wds/TableViewer/tableView.aspx?ReportId=92

Table A.2. Descriptive statistics of the input variables (normalised).

	COMPANY DIMENSION			MARKET DIMENSION			MACROECONOMIC DIMENSION
	INCOTERM	INTERMODALITY	VALUE	LOGISTIC PERFORMANCE	MARITIME CONNECTIVITY	DISTANCE	MACROECONOMIC
Mean	0,412	0,058	0,189	0,699	0,438	0,868	0,538
Standard deviation	0,160	0,033	0,133	0,022	0,015	0,040	0,017
Min	0,184	0,016	0,061	0,664	0,401	0,776	0,500
Max	0,719	0,153	0,586	0,730	0,460	0,927	0,558

Appendix 2 The macroeconomic dimension of the strategic transportation resilience Index

The first pillar of the macroeconomic dimension is Economic Stability. It consists of two variables (*Inflation* and *Exchange Rate Volatility*), changes in which have short term effects on every firḿs costs, and thus profitability. Lack of stability in these two variables make forward-looking decisions increasingly difficult, as both assuming those changes or hedging against them imply a relevant cost.

The second pillar, of a more structural nature, is Productive Efficiency. Again, it comprises two relevant variables; namely, *Total Factor Productivity* and *Labour Productivity*. Tracking their evolution is essential to forecast the capacity of a firḿs providers in a particular country to maintain (and improve) the volume and the price-quality combination of their supplies; this is particularly important for international firms that depend on a single country of origin for their imports.

The third pillar corresponds to Institutional Quality. We take three variables which affect the way business activities are conducted: the degree of *Corruption*, the *Governmental Efficiency,* and the level of *Economic Freedom*. Those institutional factors are relevant for national suppliers and even more so for international firms that decide to manufacture and/or trade for themselves in a foreign country.

Finally, we add the dimension of Resources and Costs through another three variables, *Human Capital*, *Physical Capital*, and *Labour Costs*. Whereas suitable data for the first two variables are available (see details in Table A.1), there is a lack of reliable information about wages or salaries for enough countries and years. We thus use the GDP per capita as an proxy for labour cost, as payroll is the main component of (and positively correlated with) the national income.

Table A.2.

VARIABLE	DEFINITION	SOURCE
Inflation	Annual change (CPI prices)	International Monetary Fund (IMF). World Outlook Database
Exchange Rate Volatility	Absolute value of the annual change in the countrýs nominal effective exchange rate (NEER) (bilateral nominal with the US$ if the NEER is not available)	Bank of International Settlements (BIS). Foreign Exchange Statistics.
Total Factor Productivity	4-year rolling average of the annual change in Total Factor Productivity	Groningen University Growth and Development Centre. Penn World Table 10.0
Labour Productivity	4-year rolling average of the annual change in Labour Productivity per worker (difference between real GDP growth and employment growth)	International Monetary Fund (IMF). World Outlook Database

(*continued on next page*)

(*continued*)

VARIABLE	DEFINITION	SOURCE
Governmental Efficiency	Central value for the individual indicator of Governmental Efficiency. (Values from −2.5 to 2.5, where higher value = more efficiency)	World Bank. Governance Indicators.
Corruption	Corruption Perception Index (Values from 1 to 100, where higher value = perception of less corruption)	International Transparency
Economic Freedom	Index of Economic Freedom Corruption Perception Index (Values from 1 to 100, where higher value = higher economic freedom)	Heritage Foundation
Labour Cost	Purchasing Power Parity in constant terms, 2017 international dollars (taken as an inverted proxy)	International Monetary Fund (IMF). World Outlook Database
Physical Capital	Rate of investment (as % of GDP)	International Monetary Fund (IMF). World Outlook Database
Human Capital	Index of Human Capital	Groningen University Growth and Development Centre. Penn World Table 10.0

We do not understand the vulnerability of a value chain as an absolute concept, since a firḿs need/capacity/desire to change its suppliers depends not only on their characteristics and performance, but also on their potential (or real) competitors in other countries. Specifically, for the scoring of the 10 variables in our macroeconomic dimension in every country-year pair, we first split the world economies between developed countries and emerging and developing countries.[1] Secondly, we calculate the weighted average for those two major categories of countries and for each of our 10 individual variables.[2] Finally, we take that value as the central one for every year and compare it with a countrýs value in every year. Table A.2 shows how the score for the variable-country pair in every year is obtained.[3]

Table A.3.

Variable/**Scoring**	1	2	3	4	5
Inflation (a)	Value > 40 % lower than the CV	Value 20–40 % lower than the CV	Central Value (CV) +/- 20 %	Value 20–40 % higher than the CV	Value > 40 % higher than the CV
Exchange Rate Volatility (b)	Value > 40 % lower than the CV	Value 20–40 % lower than the CV	CV +/- 20 %	Value 20–40 % higher than the CV	Value > 40 % higher than the CV
Total Factor Productivity	Value > 40 % lower than the CV	Value 20–40 % lower than the CV	CV +/- 20 %	Value 20–40 % higher than the CV	Value > 40 % higher than the CV
Labour Productivity	Value > 40 % lower than the CV	Value 20–40 % lower than the CV	CV +/- 20 %	Value 20–40 % higher than the CV	Value > 40 % higher than the CV
Governmental Efficiency	Value > 0.5 lower than the CV	Value 0.25—0.5 lower than the CV	CV +/- 0.25	Value 0.25—0.5 higher than the CV	Value > 0.5 higher than the CV
Corruption	Value > 25 % lower than the CV	Value 12.5–25 % lower than the CV	Central Value (CV) +/- 12.5 %	Value 12.5–25 % higher than the CV	Value > 25 % higher than the CV
Economic Freedom	Value > 25 % lower than the CV	Value 12.5–25 % lower than the CV	Central Value (CV) +/- 12.5 %	Value 12.5–25 % higher than the CV	Value > 25 % higher than the CV
Labour Cost	Value > 25 % lower than the CV	Value 12.5–25 % lower than the CV	Central Value (CV) +/- 12.5 %	Value 12.5–25 % higher than the CV	Value > 25 % higher than the CV
Physical Capital	Value > 25 % lower than the CV	Value 12.5–25 % lower than the CV	Central Value (CV) +/- 12.5 %	Value 12.5–25 % higher than the CV	Value > 25 % higher than the CV
Human Capital	Value > 25 % lower than the CV	Value 12.5–25 % lower than the CV	Central Value (CV) +/- 12.5 %	Value 12.5–25 % higher than the CV	Value > 25 % higher than the CV

Note: the Central Value (CV) is the weighted average of the data for the variable-year pair and for the category in which a country is included (developed or emerging/developing).

(a) For inflation, values showing *decreasing* prices of up to 1 % (more than 1 %) are marked as 4 (5), since a deflationary environment is usually considered to be negative. Rates of inflation up to 2 % are never marked more than 3, regardless of the Central Value, as we consider that value indicates price stability.
(b) For the exchange rate volatility, the absolute value of the variable is considered and equally valued, as abrupt movements of exchange rates in either direction may be equally negative for a country and a firm.

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[1] We follow the distinction established by the International Monetary Fund.

[2] The weight for each country corresponds to its share of the total global GDP based on purchasing power parity.

[3] Note that the criteria for scoring each variable, even if following the same procedure, is adapted to their different volatility or, in the case of the governmental efficiency, the way in which the original indicator (see Table 2) is built.

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