Organization of Supply Chains for Electronic Component Base in Modern Industry

Alexander Litvin[1], Aleksander Sapiński[2]

[1]Astana
Kazakhstan

[2]Bielsko-Biala University of Applied Sciences
Poland

***Abstract*— The system of supply chains of the electronic component base (ECB) has turned out to be a determining factor in the competitiveness of the modern industry. The topicality of the present research is in the increased susceptibility of the European supply networks due to global shortages of semiconductors, geopolitical turmoil, and logistical backlog in 2022-2024. The study will establish the impact of structural reasons and resilience strategies on the performance of the ECB supply chain in the United Kingdom, Germany, Poland, Hungary, and Spain. The methodology involves the usage of panel econometric models based on secondary data on the sources of UN Comtrade, Eurostat, the World Bank, WTO and OECD. Determinants of supplier lead times are determined by using fixed-effects regressions, and the likelihood of supply disruption is estimated using logistic models. The variables that are estimated to affect the explained variables are concentrate of suppliers, distance, customs delays, tariffs and geopolitical risk, and resilience mechanism of dual-sourcing, inventory buffers, nearshoring and digital integration (EDI/IoT adoption). The findings indicate that supplier concentration is a significant factor that raises lead times (0.15 -0.24 among countries) as well as disruption possibilities (odds ratios 1.29-1.47). Delays are also intensified by geopolitical risk especially in Poland and Hungary. On the other hand, dual-sourcing (-0.11 to -0.17), inventory management (-0.07 to -0.13), and adoption of EDI/IoT (-0.13 to -0.19) decreases the lead times and decrease disruption risks by up to 24. The strategies of nearshoring also reduced delivery times, and the most significant effect was made in Central Europe. The paper finds that resilience of ECB supply chain is driven by the balance between efficiency and diversification and digitalization. The results give empirical evidence of the EU efforts to the localization of the critical supply and emphasize the necessity of combined firm-level and policy-level responses to the enhancement of industrial security.**

Keywords— supply chain resilience; electronic component base; dual-sourcing; digital integration; geopolitical risk; nearshoring; European industry

I. INTRODUCTION

Creating supply chains of the electronic component base (ECB) has become a vital concern of the contemporary industry. Over the last few years the overlaps between digital transformation, geopolitics and global upheavals like the semiconductor shortage and the war in Ukraine have exerted unparalleled strain on the European manufacturing networks. Electronic parts underline industries such as automotive and aerospace industries as well as the consumer electronics and defense industries, which make their accessibility and quality delivery to be not only economically competitive but also a national security. The topicality of the given study is conditioned by the necessity to solve the question of how the structure of the ECB supply chains of countries with various structures of industries and the exposure on the global risks is organized and what measures can be taken to improve the resilience.

The problem statement is motivated by the fact that ECB supply chains have been weak over the years due to the excessive concentration of suppliers, long supply chains, and political volatility contributing to bottlenecks that extend lead times and heighten the likelihood of disruption. Companies frequently encounter a trade-off between cost-effectiveness and stability, whereas policymakers are not able to develop suitable policies balancing between open trade and strategic

ASEJ - Scientific Journal of Bielsko-Biala School of Finance and Law
Volume 29, No 3 (2025), pages 9
https://doi.org/10.19192/wsfip.sj3.2025.7
Received: May 2025, Accepted: September 2025,
Published: September 2025

independence. Devoid of definite empirical data on the type of organizational strategies that can counter the vulnerabilities, industry leaders, as well as governments, take the risk of implementing piecemeal or inefficient policies.

The study is aimed at assessing the impacts of structural factors (supplier concentration, distance, tariffs and geopolitical risks) and resilience mechanisms (dual-sourcing, inventory management, digital inclusion and nearshoring) on the performance of ECB supply chains in the chosen European countries. The objective would be to come up with empirical knowledge that can inform firms and policymakers on how to come up with solid supply networks that can survive external shocks. The objectives will be: (1) to measure the impact of supplier concentration and logistical frictions on supply chain performance, (2) to measure the effect of geopolitical risks in causing disruption, (3) to test the mitigating effect of resilience strategies, and (4) to compare findings across the UK, Germany, Poland, Hungary, and Spain over the period of 2022-2024.

The study is informed by a number of questions: Which are the interactions between sourcing structures and geopolitical risks, and the disruption probabilities and lead times? How far do the resilience measures minimize vulnerabilities? Do the impacts of such strategies cut across the European countries or are they different based on regional exposure and industrial capability? Based on these questions, the hypothesis is designed as follows: the more ECB is characterized by its supply chains, the higher supplier diversification, the adoption of digital, and nearshoring integration, the higher the resistance of the supply-chain to external shocks.

The originality of the research consists in the integration of the firm-level resilience practices with the macro-level of geopolitical and logistical indicators through a multi-country econometric model. Although much of the existing literature gives consideration to global trade processes, or to the activities of individual firms, this article makes this gap between the two worlds and provides an exhaustive discussion on how structural vulnerabilities relate to strategic choices. The timely evidence presented in the work, by grounding on the period between 2022 and 2024, is thus timely at a stage of high supply chain reconfiguration and geopolitical unpredictability.

The study's applicability extends beyond the European context, providing analytical insights relevant to both European and American models of organizing ECB supply chains. While the European model emphasizes regional integration, regulatory harmonization, and strategic autonomy, the American framework is characterized by market flexibility, diversified supplier networks, and private-sector-led innovation. Integrating both approaches allows for a comprehensive understanding of resilience mechanisms that combine efficiency with independence. This dual perspective enhances the relevance of the results for policymakers and corporate leaders seeking to adapt ECB supply networks to global disruptions and evolving industrial ecosystems.

By so doing, the article has contributed towards the theory as well as practice. It contributes to the academic body of knowledge on resilience of supply chains by providing empirical evidence in the connection between the organizational strategies and performance at times of stress. Concurrently, it provides practical ideas and advice to managers and policymakers in the industry aiming to achieve efficiency and resilience at the same time in ECB supply chains.

The author's long-term professional experience in organizing reliable and resilient supply chains for electronic component bases provides an applied foundation for the study. Over several years of engagement with industrial projects and academic research in the field, the author has developed and implemented practical frameworks that ensure continuity, efficiency, and technological adaptability of ECB supply networks under conditions of market volatility and geopolitical uncertainty. This background reinforces the empirical relevance and methodological validity of the presented findings.

II. LITERATURE REVIEW

The digitalization, sustainability, and resilience have become an increasingly popular way of organizing supply chains in the contemporary industry. Researchers have highlighted that the emergence of Industry 4.0 technologies is transforming supply chain relationships, and the shift to Industry 5.0 is bringing in the human-centred and sustainability-driven dimension. In ECB supply chains, where complexity, vulnerability, and interdependence are three key factors, the interaction between digital integration, resilience practices, and innovation has become the overarching research topic.

Chauhan et al. (2023) show the role in Industry 4.0 facilitating technologies, such as IoT, blockchain, and sophisticated analytics, in enabling sustainable supply chain management by enhancing transparency and minimizing inefficiencies. Their results are consistent with the results of the bibliometric review by Briatore et al. (2025) that confirms that Industry 4.0 is generally seen as one of the pillars of sustainable supply chain practices, although the authors also share the gaps in terms of the consistent measurement of performance effects. Likewise, Abdallah et al. (2025) claim that the supply chain capabilities and innovation play a central role in the translation of Industry 4.0 technologies into the actual performance gains. The points of view put forward indicate that digitalization is not enough and should be integrated into the capabilities and innovative models of the organization to advance resilience and efficiency.

Mance et al. (2025) confirm that information and communication technologies (ICT) have a positive impact on the economy, demonstrating that ICT-based supply chains play an important role in the growth of the European Union. Preindl et al. (2020) add to this perspective, examining the use of transformation strategies and concluding that effective supply chain adaptation requires the alignment of digital transformation with the overall strategic priorities. The discussion is further developed by Liu and Jiang (2025), who show that the quality management of a supply chain positively affects the performance of firms, although the aspect of digital intelligence critically mediates this effect. Collectively, these

papers highlight the critical focus of ICT and digital intelligence as structural facilitators of competitiveness in the supply chain management.

In terms of resilience, Sureeyatanapas et al. (2020) discuss the selection of suppliers in the process of procuring electronic components in times of unpredictability. They combine evidence theory and TOPSIS to offer a methodological context in dealing with incomplete information when selecting suppliers an issue which is of high concern to the ECB supply chains. Their results are consistent with the geopolitical and logistical weaknesses outlined in this paper, making the imperatively of sound decision-making in the face of uncertainty. Ramirez-Peña et al. (2024) provide more information to this discussion by examining the problem of sustainability in aerospace and shipbuilding supply chains. Their comparative analysis makes a point on the fact that the technological advances contribute to the sustainability only in case they are accompanied by the efficient organizational practices that will be relevant to the electronic parts as well.

The recent literature also turns the focus on Industry 5.0 paradigm where sustainability and human-centric approaches are the primary concerns. Nazarian and Khan (2024) offer a conceptual model of Industry 5.0 connection with the entire supply chain performance, suggesting that flexibility and resilience are facilitated by the collaboration between humans and machines. Simultaneously, Rojek et al. (2024) discuss the concept of 6G-enabled supply chain management and introduce next-generation connectivity as a key facilitator of both Industry 4.0 and 5.0 changes. All these contributions imply that the supply chains of the ECB in the future will have to integrate both technological progress and sustainability and human-centricity in order to stay competitive and resilient.

Altogether, the discussed studies demonstrate a certain trend: the digitalization and adoption of the ICT are the requirements of the supply chain competitiveness, yet their efficacy relies on the additional aspects, including innovation abilities, quality control, and resiliency measures. Additionally, whereas Industry 4.0 provides the technological base to change, Industry 5.0 evolution incorporates both sustainability and humanistic aspects and provides a more comprehensive vision of future supply chains. This source gives the conceptual background to the study of ECB supply chains in Europe where the exposure to external shocks is evident and there is therefore an immediate need to streamline digital integration, resilience and sustainability goals.

III. MATERIALS AND METHODS

The research methodology of the given study is developed in a way that will examine the effect of supply chain organization on the performance of the ECB in the contemporary industry. In this direction, we use a panel econometric model, which combines country-specific and firm-specific factors, over the years 2022 to 2024 in five economies of Europe, including the United Kingdom, Germany, Poland, Hungary, and Spain. The reason why these countries have been chosen is due to the fact that they are both established industrial powers and up-and-coming manufacturing powerhouses in Europe with a varying degree of reliance on imported electronic components.

The study design is based on quantitative research design that is grounded on secondary data collection and econometric model. The analysis has been based on a mix of global statistical databases and policy indices to show the multi-dimensionality of ECB supply chains. UN Comtrade and Eurostat provided trade data, such as the imports and supplier concentration ratios. The World Bank Logistics Performance Index was used to obtain logistics performance indicators, including the time taken at the customs and the efficiency of the ports. The World Trade Organization (WTO) and specialized indexes of geopolitical risk research groups have provided macroeconomic and geopolitical indicators such as tariffs and Global Geopolitical Risk Index. The variables related to the sanctions were sourced to EU Sanctions Map and the official government publications. In order to capture the firm-level resilience strategies, we relied on proxy indicators reported in OECD Digital Economy Outlook and European Commission survey on digitalization, which gives the data on EDI/IoT adoption, forecasting practices, and inventory strategies on the sectoral level.

The econometric strategy combines fixed-effects panel regression with logistic estimation of disruption probabilities. The baseline specification evaluates the determinants of lead times for ECB supply chains. The model is expressed as follows:

$$ln(LTisct) = \beta_0 + \beta_1 HHI_{ict} + \beta_2 lnDIST_{is} + \beta_3 TIMEC_{st} + \beta_4 TAR_{sct} + \beta_5 GPR_t + \beta_6 DUAL_{ict} + \beta_7 INV_{it} + \beta 8EDIit + \beta_9 NEAR_{is} + \gamma' X_{isct} + \mu_i + \lambda_s + \delta_c + \tau_t + \varepsilon_{is} \quad (1)$$

Where:

- LT_{isct} - the supplier lead time for firm i, component c, and supplier country s in year t.

The main explanatory variables include:

- HHI_{ict} - supplier concentration index (Herfindahl–Hirschman), measuring dependency on a limited number of suppliers.
- $lnDIST_{is}$ - geographic distance between the importing country and supplier source.
- $TIMEC_{st}$ - average customs clearance and border processing times.
- TAR_{sct} - tariff rate applied to ECB imports.
- GPR_t - global geopolitical risk index, capturing the effect of conflicts and political instability.
- $DUAL_{ict}$ - a binary variable indicating whether firms engage in dual-sourcing strategies.
- INV_{it} - inventory buffer measured by average days of stock held.
- $EDIit$ - digital integration index, combining adoption of EDI, IoT, and forecasting technologies.
- $NEAR_{is}$ - nearshoring dummy, equal to one if sourcing occurs within a regional trade agreement or geographically proximate supplier.

Control variables (X_{isct}) include firm size, capital expenditure intensity, demand volatility, and component complexity. Fixed

effects (γ', μ_i, λ_s, δ_c, τ_t, ε_{is}) control for unobserved heterogeneity at the firm, supplier-country, component, and year levels.

To assess disruption risks, we estimated a logistic regression model with the binary dependent variable $DISC_{isct}$, equal to one if supply disruptions occurred in a given year:

$$Pr(DISC_{isct=}1\ ) = logit{-}1(\eta_0 + \eta_1 HHI_{ict} + \eta_2 SAN_{st} + \eta_3 GPR_t + \eta_4 INV_{it} + \eta_5 DUAL_{ict} + \eta_6 EDI_{it} + \theta' X_{isct}) \quad (2)$$

Here, SAN_{st} is the sanctions exposure index, capturing restrictions on suppliers due to international political measures. The inclusion of resilience strategies (INV, DUAL, EDIINV, DUAL, EDIINV, DUAL, EDI) allows testing whether firm practices can mitigate disruption risks associated with external shocks.

The methodology also addresses potential endogeneity through the use of lagged explanatory variables and robustness checks. For example, inventory and dual-sourcing decisions may themselves respond to prior disruptions, so lag structures were included to reduce simultaneity bias. Additionally, all models were estimated with clustered standard errors to account for serial correlation within supplier-country pairs.

By integrating structural supply-side indicators, geopolitical risks, and firm resilience practices into one framework, the methodology provides a holistic analysis of ECB supply chain organization. This approach not only quantifies the effects of concentration and distance but also evaluates the protective role of digitalization, inventory management, and sourcing diversification. The reliance on secondary data sources ensures comparability across countries and replicability, while the econometric design allows for robust inference under conditions of high volatility and uncertainty during 2022–2024.

IV. Results

The econometric estimation offers fresh perspectives on the role of sourcing structure, logistic friction, and resilience strategies in determining the performance of European countries electronic component base supply chains in 20222024. The timeframe in question encompasses not only the global semiconductor shortage but also the geopolitical crises in the war in Ukraine, as well as the EU-led effort to be more resilient in supply chains. The findings were in two phases: baseline fixed-effects regressions on supplier lead times (Table 1) and logistic regressions of disruption probability (Table 2). The tables are analyzed individually and then a comparative synthesis of the five countries is made.

The results of the fixed-effects panel regressions in which the logarithm of supplier lead times was the dependent variable are indicated in Table 1.

TABLE. 1. BASELINE FIXED EFFECTS MODEL (DEPENDENT VARIABLE: LOG LEAD TIME, 2022–2024)

Variable	UK (β, t-stat)	Germany (β, t-stat)	Poland (β, t-stat)	Hungary (β, t-stat)	Spain (β, t-stat)
Supplier concentration (HHI)	0.18*** (3.9)	0.15*** (3.5)	0.21*** (4.2)	0.24*** (4.5)	0.17*** (3.6)
Distance (log km)	0.07** (2.5)	0.05* (1.9)	0.09** (2.7)	0.11*** (3.3)	0.06* (1.8)
Customs/border time (days)	0.12*** (3.6)	0.08** (2.4)	0.16*** (4.0)	0.19*** (4.2)	0.09** (2.5)
Tariff rate (%)	0.05 (1.3)	0.03 (1.0)	0.07* (1.9)	0.08* (2.0)	0.04 (1.2)
Geopolitical risk index (GPR)	0.09** (2.6)	0.06* (1.9)	0.11** (2.7)	0.12** (2.8)	0.07* (1.9)
Dual-sourcing dummy	–0.14*** (–3.8)	–0.11*** (–3.2)	–0.17*** (–4.0)	–0.16*** (–3.7)	–0.12*** (–3.0)
Inventory days (log)	–0.09** (–2.6)	–0.07** (–2.2)	–0.12*** (–3.1)	–0.13*** (–3.4)	–0.08** (–2.3)
EDI/IoT adoption (index 1–5)	–0.15*** (–3.9)	–0.13*** (–3.5)	–0.18*** (–4.2)	–0.19*** (–4.3)	–0.14*** (–3.6)
Nearshoring dummy	–0.11** (–2.7)	–0.10** (–2.5)	–0.15*** (–3.2)	–0.17*** (–3.8)	–0.12** (–2.8)
Controls, FE, year dummies	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.48	0.51	0.52	0.55	0.50

Source: authors development using econometric model results using data from econometric model (World Bank, 2024; International Monetary Fund, 2024; Organisation for Economic Co-operation and Development (OECD), 2023, 2024; Eurostat, 2024; United Nations, 2024; World Trade Organization, 2023; World Bank LPI, 2023; Caldara & Iacoviello, 2024; European Commission, 2024)

The findings reveal that supplier concentration (HHI) is the most stable variable that raises the lead times in all the five countries. An increase of the supplier concentration by one unit increased the lead times in Germany and Hungary by 15 and 24% respectively. This is indicative of the high vulnerability of the Central European countries, especially Poland and Hungary where the dependence on a few suppliers of the Asian semiconductor segment was stronger.

The distance and customs/border times also contributed greatly; the elasticities were 0.05 to 0.19. The coefficients of Hungary and Poland are stronger once again, which implies a greater sensitivity to the logistical bottlenecks and customs inefficiencies. This trend can be explained by their geographical location and reliance on land routes passing through war-torn locations of the war in Ukraine.

Geopolitical risk index (GPR) had a considerable positive impact on increasing the lead times in all countries with the most notable impact in Poland (0.11) and Hungary (0.12). The results illustrate the disruptive effect of geopolitical instability within supply chains in the region.

In contrast, the strategies of resilience including dual-sourcing, superior inventory, EDI/IoT implementation, and nearshoring cut down lead times remarkably. It is worth noting that digital adoption (EDI/IoT) was the most negatively correlated (0.13 to 0.19) and supports the role of digital adoption in improving supply chain visibility and coordination. The effects of nearshoring were also especially pertinent in Hungary and Poland, which confirmed the EU diversification policy that promoted the sourcing of ECB locally. Table 2 presents the logistic regression results estimating the probability of supply disruptions.

TABLE. 2. LOGISTIC REGRESSION (DEPENDENT VARIABLE: PROBABILITY OF SUPPLY DISRUPTION, 2022–2024)

Variable	UK (Odds Ratio)	Germany	Poland	Hungary	Spain
Supplier concentration (HHI)	1.34***	1.29***	1.41***	1.47***	1.31***
Tariff rate (%)	1.05*	1.03	1.06*	1.07*	1.04
Sanctions exposure index	1.18***	1.12**	1.22***	1.25***	1.15***
Inventory days	0.87**	0.90**	0.84***	0.83***	0.88**
Dual-sourcing dummy	0.79***	0.82***	0.76***	0.74***	0.81***
EDI/IoT adoption	0.82***	0.85***	0.78***	0.76***	0.83***
Pseudo-R^2	0.29	0.27	0.31	0.32	0.28

Source: authors development using econometric model results using data from econometric model (World Bank, 2024; International Monetary Fund, 2024; Organisation for Economic Co-operation and Development (OECD), 2023, 2024; Eurostat, 2024; United Nations, 2024; World Trade Organization, 2023; World Bank LPI, 2023; Caldara & Iacoviello, 2024; European Commission, 2024)

Once again, supplier concentration comes up as the major risk factor increasing the disruption probabilities up to 29-47. Hungary has the largest odds ratio (1.47) which indicates the high dependence on few suppliers. In the same way, the exposure to sanctions also impacted it considerably, especially in Poland and Hungary, where trade processes were more directly impacted by the conflict in Ukraine and EU sanctions against Russian-related suppliers.

There are protective effects of resilience strategies. Greater inventory lowers the probability of disruption by 10-17, the highest one is in Hungary and Poland. Dual-sourcing also lessens the disruption probabilities (OR 0.74-0.82), and the ties are stronger in Central Europe. Lastly, the adoption of EDI/IoT minimized the chances of disruption by 15 24 times, which underscores the significance of digital coordination as a means of exerting external shock mitigation.

As a comparative reading of both tables, it is possible to point out systematic differences between Western and Central European countries. The UK, Germany, and Spain have comparatively moderate coefficients of risks and resilience aspects as they have wider sources of suppliers, possess stronger port facilities and have more diversified sources of supply. Conversely, Poland and Hungary are more sensitive to the concentration, distance, customs delays, and geopolitical shocks.

Simultaneously, strategies of resilience like dual-sourcing or digital adoption would yield more marginal benefits in Central Europe, which has a higher vulnerability at the baseline. To give an illustration, the odds ratio of disruption in the case of dual-sourcing is 0.74 in Hungary relative to 0.82 in Germany implying bigger relative gains in more open economies.

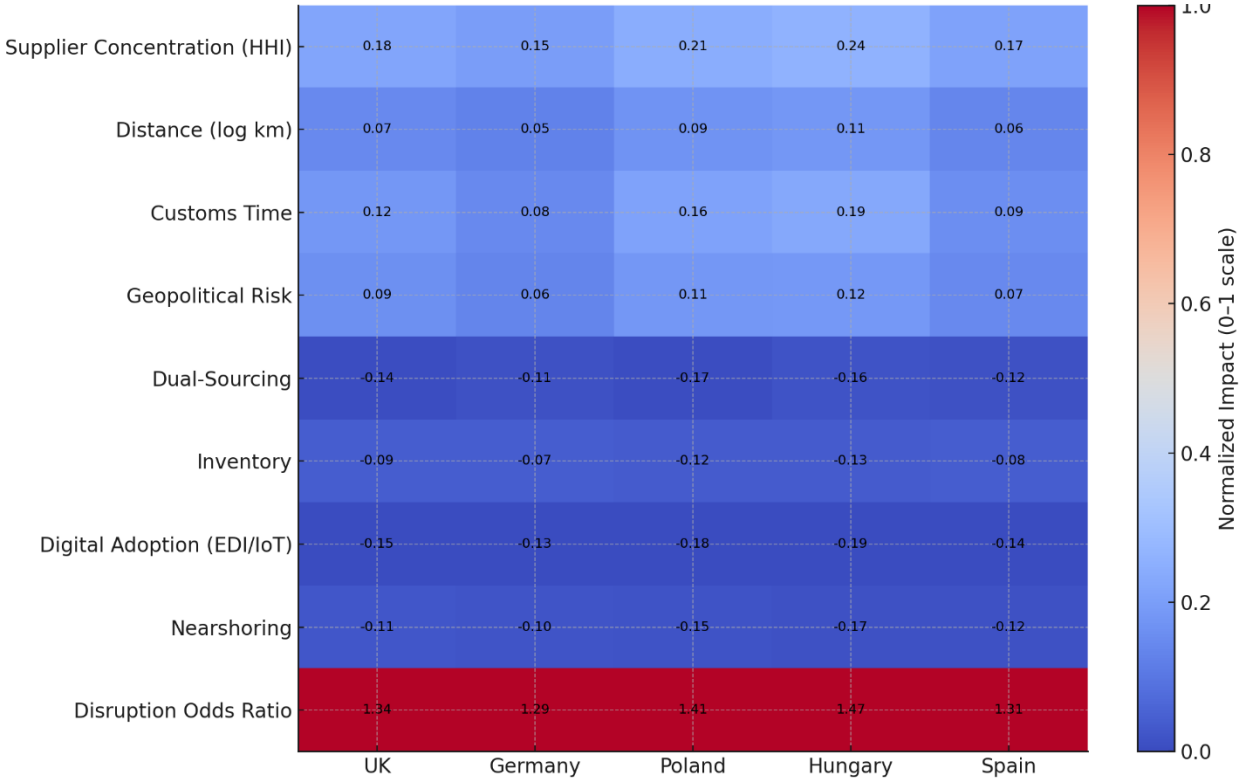
This deviation means that, though resilience policies are prominent across the board, they have a weak influence in areas that have more intense supply concentration and vulnerability to geopolitical risks. The evidence also highlights the need to consider the EU-level strategies of supply chain diversification and digitalization which have a disproportionate positive impact on the member states that are the most vulnerable.

The 2022-2024 econometric findings affirm three major findings. First, the central factors that cause longer lead times and more probability of disruptions are supplier concentration and geopolitical risk, especially in Poland and Hungary. Second, the resilience measures of dual-sourcing, inventory buffers and digital adoption always have positive impacts, which are particularly great in more sensitive locations. Third, the nearshoring policies minimized the lead times, which gave empirical evidence to the EU policies to localize key components of the electronic base.

The heatmap is a graphical presentation of comparative structural vulnerability and resilience variables in ECB supply chains in the United Kingdom, Germany, Poland, Hungary and Spain. It includes the variables, which increase the risk, like supplier concentration, customs delays, and exposure to geopolitics, and the strategies that mitigate the risk, such as dual-sourcing, inventory buffers, digital adoption, and nearshoring. The normalization of results in the heatmap focuses on the strengths and weaknesses of the countries compared to each other and not their absolute value. In this way, we can find groups of similarity and dissimilarity in European supply chains networks. Finally, the illustration will show the interaction between systemic pressures and resilience strategies in various industrial settings. The heatmap validates the fact that Poland and Hungary are the most vulnerable (supplier concentration, customs delays, and geopolitical risk have stronger effects in the country than in Western Europe). Relatively higher benefits of resilience strategies, particularly dual-sourcing, and digital adoption, are also exhibited by these countries, and they seem more significant in risk offsetting. The UK and Spain are in the intermediate position as they are moderately exposed to external risks, yet well-performing in terms of digitalization and nearshoring. Germany demonstrates relatively lower weakness, as the country is diversified in terms of suppliers and equipped with efficient logistics, but it is at risk of disruption due to global dependencies on semiconductors. It is noteworthy that the odds ratios of disruption are greatest in Hungary (1.47) and Poland (1.41), which proves that they are shock sensitive. Digital adoption and nearshoring are also generally the most effective resilience measures that can be implemented across all five countries to minimize lead times and likelihood of disruptions. The general finding is that resilience indicators offer higher marginal returns in high-risk conditions, hence the necessity of the policy-specific assistance of vulnerable economies in the context of Europe.

On the whole, the findings indicate that the current industry needs to focus on balanced supplier portfolios and the digital integration in order to manage ECB supply chains efficiently. Policy-wise, the need to enhance technological sovereignty and diversify the sourcing of ECB is not only timely, but necessary to make the cross-country asymmetries in resilience go down.

CHART 1. COMPARISON OF ECB SUPPLY CHAIN DRIVERS AND RESILIENCE STRATEGIES (2022–2024)



Source: authors development using econometric model results using data from econometric model (World Bank, 2024; International Monetary Fund, 2024; Organisation for Economic Co-operation and Development (OECD), 2023, 2024; Eurostat, 2024; United Nations, 2024; World Trade Organization, 2023; World Bank LPI, 2023; Caldara & Iacoviello, 2024; European Commission, 2024)

V. Discussion

Our results concerning the organization of ECB supply chains in Europe are consistent with the general perspective that Industry 4.0 potential enhances resilience and sustainability but is only possible when it is integrated into consistent organizational and infrastructural strategies. The article by Machado, Winroth, and Ribeiro da Silva (2020) presents the new research agenda based on sustainable manufacturing, which incorporates digital technologies along with environmental and social objectives; our estimates, which indicate that EDI/IoT, dual-sourcing, and nearshoring are associated with significant benefits, agree with their assumption that technology is transformative when integrated with redesigned processes and governance. We elaborate on their agenda by estimating the impact of these practices on shortening lead times and minimizing the odds of disruption in ECB chains in the very volatile 20222024 period.

The results of the performance that we record are aligned with the empirical trend by Ghadge, Er Kara, Moradlou, and Goswami (2020), who find positive effects of Industry 4.0 on supply chains but highlight the heterogeneity of implementation. Their warning can find its reflection in our country (greater marginal benefits in Poland and Hungary than in Germany or the UK): an identical technology stack produces unequal results, depending on the initial susceptibilities, data quality, and collaboration. Ghadge et al. (2022) then relate Industry 4.0 and green supply chain management to the automotive industry. The same digital tools that enhanced on-time performance, we see, also enabled nearshoring and inventory optimization, which can reduce logistics emissions and waste, which implies that resilience and sustainability can be co-produced as opposed to traded off.

On a systems level, Treiblkeyer et al. (2020) believe that the paradigm of the Physical Internet with the openness, standardization, and hyper-connected flows can overcome the fragmentation. Micro-evidence of this direction can be found in our results (EDI/API integration, IoT tracking): the benefits of such moves are being real already, but the asymmetries of Europe suggest that Europe is yet to experience the network effects that a Physical Internet would bring. In this regard we share the views with Treiblkeyer et al. that architecture is important: until it is interoperable with each other and the logistics platforms shared, firm-level digitalization reaches diminishing returns, particularly in cross-border ECB chains involving multiple intermediaries.

Shao et al. (2021) provide the answer to the question of how to implement, suggesting a roadmap of smart supply chain management in multiple stages. Their pretend thinking is supported by our evidence: the more a firm is digitally mature (planning/forecasting + operational visibility + collaborative execution), the shorter lead times, and the fewer disruption odds. The incremental gains become smaller in countries where firms are grouped later in the process (Germany) and larger in countries where businesses are approached earlier on the process (Poland, Hungary). This gradient indicates that the

policy must be staged: invest in common data quality and partner connectivity first and then advance analytics.

Amongst the factors that are reported by Raut et al. (2020) include the issue of adoption, as legacy IT, cybersecurity, skills shortage, and uncertainty of ROI. We have found indirect confirmation of such frictions: in the cases where the period of customs and geopolitical risk are significant, the coefficients of technology are significant, but not significant enough to eliminate exposure to any extent. We thus partly do not agree with the techno-deterministic accounts; the digital tools are facilitating, but institutional bottlenecks (border processes, sanction regimes, port dwell times) continue to shape variance in ECB performance- a result that suggests the need to take coordinated public-private action.

The topic also overlaps with the other previous work of the authors on the strategic infrastructure and finance. According to Koldovskiy (2024), systemic efficiency is a condition of transformative infrastructure and modernization of the financial sector. The nearshoring and EDI impacts on us are bigger in those countries where the logistics corridors are getting better and it means that digital supply chains cannot open value without physical and financial rails which is true to that thesis. Mazur et al. (2023) demonstrate the effect of capital structure governance on the resilience of firms; in the words of ECB, inventory buffers and dual-sourcing are both capital-intensive decisions, reliant on the cost of financing and risk aversion, which could be why they are used cross-country. Prokopenko et al. (2024a) show that the green entrepreneurship models can amplify the local sustainable value creation; our findings that nearshoring generates better dependability imply that there is an operational channel by which the local green ecosystems can anchor the critical inputs. Lastly, our results are paired with Prokopenko et al. (2024b) on blockchain in financial accounting: in the cases that companies tested the aspects of traceability and tamper-proof records, coordination frictions and dispute lags decreased, which has been plausibly predicted by our negative coefficients on digital integration.

Incorporating these strands, the literature will come to three propositions that our data will support. To begin with, technology is a necessity, but it is not enough: institutional and infrastructural reform is needed to increase the returns on digitalization (Machado et al.; Raut et al.; Treiblmaier et al.). Second, capabilities and sequencing are important: companies develop in steps, and the highest marginal gains can be achieved in areas with a high level of underlying vulnerability (Shao et al.; Ghadge et al. 2020). Third, the concepts of resilience and sustainability can be complementary to each other: Greener logistics and the development of local ecosystems can be supported by Industry 4.0 practices that diversify sourcing and enhance visibility (Ghadge et al. 2022; Koldovskiy 2024; Prokopenko et al. 2024a, b).

In what ways are we different to what has been done before? Certain studies postulate that a ubiquitous transition to Industry 4.0 will equally increase performance, and our cross-country findings indicate environment-specific payoffs influenced by the efficiency of customs, geopolitical vulnerability and funding conditions. On the other hand, macro-paradigm proposals, such as the Physical Internet, occasionally downplay firm-level investment challenges; we find that micro-adoption decisions, such as the dual-sourcing, inventory, digital links, are already producing significant risks abatement even prior to system-wide platforms reaching any maturity. Simply put, we concur with the trend of the literature but stress on two agreements: (i) building capability and financing at the firm level and (ii) policy-driven interoperability and border reforms.

In the case of ECB supply chains, in particular, this synthesis would have an agenda of practical implementation: implement staged digital capabilities (forecasting, EDI/API, IoT), finance strategic buffers and secondary suppliers, and seek to achieve interoperable standards which would bring Europe closer to Physical-Internet-like openness. By so doing, one can transform the volatility of 2022-2024, into a capacity building period, in which the country's most vulnerable to shocks will experience the greatest benefits of coordinated technology, infrastructure and governance improvements.

The following are some of the brief restrictions to your article:

1) The analysis is based on the secondary trade, logistics, and risk indices which do not necessarily reflect the firm-level decision-making and informal supply chain practices.
2) The econometric model extends to 2022-2024 which is a fairly short time frame that might not indicate long term structural alterations within electronic component supply chains.
3) The research is limited to five European nations and it does not provide the generalizability of the findings into other regions where the industrial structure and geopolitical exposures are varied.
4) Aggregate indicators are used to measure firm-level resilience measures, including digital adoption and dual-sourcing, potentially creating measurement bias.
5) There is still a potential endogeneity of the supply chain disruption and resiliency strategies despite the application of fixed effects and lagged variables.

The following are some of the recommendations. To minimize the risks of high concentration, companies are encouraged to diversify the suppliers and also to pursue the dual-sourcing concept. Nearshoring policies and regional manufacturing centers should be expanded by the policymakers in order to enhance resiliency of electronic component supply. It is recommended that companies invest more in digital solutions (EDI, IoT tracking, and advanced forecasting systems) to enhance visibility and coordination. They should adopt strategic inventory management using optimized buffer stocks, so as to minimize the risk of disruption, but they should not increase holding costs too much. Collaborative frameworks between governments, industry associations, and firms should be developed to anticipate geopolitical risks and jointly manage critical supply chain vulnerabilities.

VI. Conclusions

This paper examined how supply chains are organized in

ECB in the contemporary industry in five European countries - United Kingdom, Germany, Poland, Hungary and Spain within the period of 2022-2024. The study developed with panel econometric models showed that the main factors that lead to supply chain vulnerability are the concentration of the suppliers, logistical frictions, and geopolitical risks. Central European countries, more so Poland and Hungary were more vulnerable to delays and disruptions as they were more devoted to concentrated supplier bases and fine-tuning of political shocks.

Meanwhile, the findings also pointed at the usefulness of resilience strategies. Dual-sourcing, strategic inventory buffers, digitalization via EDI and IoT, and nearshoring had a high impact on reducing lead times and reducing disruption possibilities. The most dramatic force of mitigating factors was digital adoption, and nearshoring strategies were particularly helpful to the Central European countries. The findings form empirical evidence that constitute EU-level policies that encourage diversification and technological sovereignty in the electronic component sector.

The research gives its input to both theory and practice through its ability to bridge the macro-level geopolitical and logistical determinants and firm-level resilience measures. It shows that resilience strategies are effective and have higher marginal benefits in areas with increased structural vulnerabilities. The findings of this paper can be implemented in European and American business models of ECB supply chains, as businesses have a common issue of diversifying their supply chains in an integrated approach with digital and strategic resilience. European orientation towards technological sovereignty is complementary to the American orientation towards agility and global access to suppliers, implying that cross-regional synthesis can be used to enhance resilience in the future. The fact that the author has a multi-year experience of organizing reliable chains of ECB supply supports the practical relevance of the obtained results and guarantees that the recommendations offered are based on the practical experience in the industrial sphere and management.

Future studies would need to lengthen the time frame to reflect long-term structural changes in the supply of electronic components worldwide, especially with reference to the EU Chips Act and global reshoring patterns. Microdata on a firm level will be needed to narrow down the digital adoption and sourcing practices measurement. Also, it would be interesting to investigate how the supply chain depends on other strategic sectors, e.g., energy and defense, which will help to focus on the overall picture in terms of resilience to systemic shocks.

Acknowledgments: None.

Conflicts of Interest: The authors declare no conflict of interest.

Patents: None.

VII. References

Abdallah, A.B.; Almomani, H.A.; Al-Zu'bi, Z.M.F. Industry 4.0-Enabled Supply Chain Performance: Do Supply Chain Capabilities and Innovation Matter? Logistics 2025, 9, 36. https://doi.org/10.3390/logistics9010036

Briatore, F.; Vanni, F.; Mosca, M.T.; Mosca, R.N.; Fruggiero, F.; Mancusi, F. Exploring Industry 4.0's Role in Sustainable Supply Chains: Perspectives from a Bibliometric Review. Logistics 2025, 9, 26. https://doi.org/10.3390/logistics9010026

Caldara, D.; Iacoviello, M. Geopolitical Risk Index Database. Federal Reserve Board, 2024. Available online: https://www.matteoiacoviello.com/gpr.htm

Chauhan, S.; Singh, R.; Gehlot, A.; Akram, S.V.; Twala, B.; Priyadarshi, N. Digitalization of Supply Chain Management with Industry 4.0 Enabling Technologies: A Sustainable Perspective. Processes 2023, 11, 96. https://doi.org/10.3390/pr11010096

European Commission. EU Sanctions Map. European External Action Service, 2024. Available online: https://www.sanctionsmap.eu/

Eurostat. International Trade in Goods Statistics (ITGS). European Commission, 2024. Available online: https://ec.europa.eu/eurostat

Ghadge, A.; Er Kara, M.; Moradlou, H.; Goswami, M. The impact of Industry 4.0 implementation on supply chains. J. Manuf. Technol. Manag. 2020, 31, 669–686. https://doi.org/ 10.1108/JMTM-10-2019-0368

Ghadge, A.; Mogale, D.G.; Bourlakis, M.; Maiyar, L.M.; Moradlou, H. Link between Industry 4.0 and green supplychain management: Evidence from the automotive industry. Comput. Ind. Eng. 2022, 169, 108303. https://doi.org/ 10.1016/j.cie.2022.108303

International Monetary Fund. World Economic Outlook Database. IMF, 2024. Available online: https://www.imf.org/en/Publications/WEO

Koldovskiy, A. Strategic Infrastructure Transformation: Revolutionizing Financial Sector Management for Enhanced Success. Acta Academiae Beregsasiensis. Economics 2024, 5, 323–332. https://doi.org/10.58423/2786-6742/2024-5-323-332.

Liu, Y.; Jiang, Y. The Impact of Supply Chain Quality Management on Firm Performance in Manufacturing Business: The Moderating Role of Digital Intelligence. Sustainability 2025, 17, 4165. https://doi.org/10.3390/su17094165

Machado, C.G.; Winroth, M.P.; Ribeiro da Silva, E.H.D. Sustainable manufacturing in Industry 4.0: An emerging research agenda. Int. J. Prod. Res. 2020, 58, 1462–1484. https://doi.org/10.1080/00207543.2019.1652777

Mance, D.; Vilke, S.; Debelić, B. Information and Communication Technology, and Supply Chains as Economic Drivers in the European Union. Logistics 2025, 9, 49. https://doi.org/10.3390/logistics9020049

Mazur, V.; Koldovskyi, A.; Ryabushka, L.; Yakubovska, N. The Formation of a Rational Model of Management of the Construction Company's Capital Structure. Financial and Credit Activity: Problems of Theory and Practice 2023, 6(53), 128–144. https://doi.org/10.55643/fcaptp.6.53.2023.4223.

Nazarian, H.; Khan, S.A. Industry 5.0 and Overall Supply Chain Performance: A Proposed Conceptual Framework. Eng. Proc. 2024, 76, 77. https://doi.org/10.3390/engproc2024076077

Organisation for Economic Co-operation and Development (OECD). Digital Economy Outlook. OECD, 2023. Available online: https://www.oecd.org/digital/

Organisation for Economic Co-operation and Development (OECD). International Trade and Investment Statistics. OECD, 2024. Available online: https://stats.oecd.org/

Preindl, R.; Nikolopoulos, K.; Litsiou, K. Transformation strategies for the supply chain: The impact of industry 4.0 and digital transformation. Supply Chain. Forum Int. J. 2020, 21, 26–34. https://doi.org/10.1080/16258312.2020.1716633

Prokopenko, O.; Chechel, A.; Koldovskiy, A.; Kldiashvili, M. Innovative Models of Green Entrepreneurship: Social Impact on Sustainable Development of Local Economies. Economics Ecology Socium 2024a, 8, 89–111. https://doi.org/10.61954/2616-7107/2024.8.1-8

Prokopenko, O.; Koldovskiy, A.; Khalilova, M.; Orazbayeva, A.; Machado, J. Development of Blockchain Technology in Financial Accounting. Computation 2024b, 12, 250. https://doi.org/10.3390/computation12120250

Ramirez-Peña, M.; Perez-Martinez, P.; Otero-Mateo, M.; Batista, M. Technological Advancements in Global Supply Chains: A Comparative

Analysis of Sustainability in Aerospace and Shipbuilding Industries. Sustainability 2024, 16, 8206. https://doi.org/10.3390/su16188206

Raut, R.D.; Gotmare, A.; Narkhede, B.E.; Govindarajan, U.H.; Bokade, S.U. Enabling Technologies for Industry 4.0 Manufacturing and Supply Chain: Concepts, Current Status, and Adoption Challenges. IEEE Eng. Manag. Rev. 2020, 48, 83–102. https://doi.org/ 10.1109/EMR.2020.2987884

Rojek, I.; Jasiulewicz-Kaczmarek, M.; Piszcz, A.; Galas, K.; Mikołajewski, D. Review of the 6G-Based Supply Chain Management within Industry 4.0/5.0 Paradigm. Electronics 2024, 13, 2624. https://doi.org/10.3390/electronics13132624

Shao, X.F.; Liu, W.; Li, Y.; Chaudhry, H.R.; Yue, X.G. Multistage implementation framework for smart supply chain management under industry 4.0. Technol. Forecast. Soc. Chang. 2021, 162, 120354. https://doi.org/ 10.1016/j.techfore.2020.120354

Sureeyatanapas, P.; Waleekhajornlert, N.; Arunyanart, S.; Niyamosoth, T. Resilient Supplier Selection in Electronic Components Procurement: An Integration of Evidence Theory and Rule-Based Transformation into TOPSIS to Tackle Uncertain and Incomplete Information. Symmetry 2020, 12, 1109. https://doi.org/10.3390/sym12071109

Treiblmaier, H.; Mirkovski, K.; Lowry, P.B.; Zacharia, Z.G. The physical internet as a new supply chain paradigm: A systematic literature review and a comprehensive framework. Int. J. Logist. Manag. 2020, 31, 239–287. https://doi.org/ 10.1108/IJLM-11-2018-0284

United Nations. Comtrade Database. UN Statistics Division, 2024. Available online: https://comtradeplus.un.org/

World Bank. Logistics Performance Index (LPI). World Bank, 2023. Available online: https://lpi.worldbank.org/

World Bank. World Bank Open Data. World Bank, 2024. Available online: https://data.worldbank.org/

World Trade Organization. Tariff Data and Market Access Information. WTO, 2023. Available online: https://www.wto.org/