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CRACKS IN THE CHAIN: MAPPING EUROPEAN IMPORT DEPENDENCIES IN GLOBAL INDUSTRIAL NETWORKS

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ABSTRACT

The tension between the benefits of trade openness and the need for national autonomy has been a constant factor in economic relations among nations. Global supply chains intensify this tension by both enhancing the benefits of trade specialization and amplifying the ripple effects of disruptions across production networks, even when certain nodes are not directly linked to foreign markets. In an era of overlapping crises and growing political fragmentation, it is crucial to reinforce supply chains—particularly in strategic sectors that underpin the green and digital transition.

Thus, it is necessary to identify the products most exposed to supply chain disruption. In this article, we reconsider and expand the approach proposed by the European Commission to identify critical dependencies at the product level for the European Union as a whole, in comparison with other major world economies. From an empirical point of view, we add a set of criteria to identify vulnerable supply chains for the individual E.U. member states, which allows us to investigate other layers of vulnerabilities, comparing those common between European economies and the EU as whole and those specific to each member state. From a methodological point of view, we add additional selection criteria: the risk profile of supplier countries, and the potential for import diversification.

By leveraging a dataset that gathers information on bilateral trade flows for over 5,000 products (at the 6-digit level) traded among more than 200 countries, we apply the defined criteria to the aggregate of the European Union, comparing it with the two major trading partners, China and the USA, as well as with E.U. member states.

Overall, the analysis suggests that import concentration is the most binding of all constraints identified, selecting about 50% of the set of critical products. Differences emerge in countries' ability to diversify the country of origin of their imports, both at the global level and between E.U. member states, and concerning the capacity substitute imports with exports, particularly between China and the U.S., with the latter characterized by a higher trade deficit. Moreover, the main European industrial economies display different potential substitutability of extra-EU imports with intra-EU trade.

However, over the past ten years, none of the countries analyzed have consistently diversified the origin of their imports. Trade vulnerabilities emerged for all the economies considered (for some more than others), regardless of their size. Indeed, critical dependencies seem to be mainly the result of long-term choices involving specialization, reallocation of international production chains, and efficiency-seeking in selected trade partners. For Europe and the U.S., this process is closely tied to the growth of emerging countries, with China at the forefront.

Focusing on a set of intermediate and capital products selected as critical for European industry in most of the last six years, it is also possible to further characterize dependencies in terms of industrial inputs. We evaluate their strategic relevance, and the geopolitical and climate risks attached, related to the countries from which these products are imported. Finally, through an iterative algorithm that redistributes market share among all existing exporters worldwide, besides those already exploited, we investigate whether alternative suppliers of these products are available to diversify imports and decrease trade dependencies.

Keywords: Industrial strategic autonomy; global value chain; foreign dependencies; import concentration; critical raw material

JEL: F14, F15

1. Introduction

The pandemic and the Russian invasion of Ukraine have highlighted the vulnerability of supply chains and the importance of the strategic autonomy of countries or macro-regions, given the complexity of global value chains, fragmented into numerous specific steps, often geographically concentrated. Business activity and household consumption have been found to be vulnerable to specific products and input supplies, which can be essential for certain sectors and supply chains and may come from countries that are geopolitically distant and/or strategic competitors.

The fragility of global value chains was already emerging before the appearance of COVID-19. For example, in 2011, the devastating earthquake in Japan, the subsequent Fukushima nuclear accident and the great floods in Thailand had already highlighted the existence of specific bottlenecks in the global production network. On the one hand, the production of electronic devices slowed down in many countries due to the flooding of Thai factories producing hard disks, which led to a decrease in exports and a prolonged increase in the price of an intermediate good for which Thailand is the second largest producer in the world after China. On the other hand, global manufacturing in the automotive and electronics sectors was affected by the shortage of certain components in which Japan plays a key role, with cascading effects on the production lines of various global car manufacturers such as Honda, Opel, Nissan and General Motors.

Thus, there was an early literature addressing the problem of the propagation of localized supply shocks through supply chains, often exacerbated by lean inventory management and just-in-time production models. For example, Carvalho, Nirei and Saito (2014) examined company-level data before and after the 2011 Japanese earthquake to investigate the propagation of exogenous shocks through national supply chains, both downstream and upstream of directly affected businesses. Korniyenko et al. (2017) developed a pre-covid 'universal' strategy for identifying, through network analysis methods, the products most at risk of supply shock in global trade, based on three parameters used to measure the vulnerability of a country's imports.

With COVID and the Russo-Ukrainian conflict, particular emphasis has been placed on strategic dependencies, i.e. those products with a high risk of supply interruption that concern areas of economic activity considered central to the interests and prospects of the economy and the society as a whole. This strategic dimension is strongly connected to social and environmental goals and, therefore, to industrial policy, as it intervenes decisively in business activities and the broad structure of production and consumption. Critical dependencies have thus become central in the strategy of the main world economies. Different approaches have been proposed to identify the most vulnerable supply chains and strategic products.

For example, Bonneau and Nakaa (2020) and Jaravel and Méjean (2021) analyze the French extra-EU dependencies (for the French Treasury and the French Council of Economic Analysis, respectively). The first paper uses two product-level criteria, the level of import concentration and network commercial centrality (taking up the measure of risk of centrality proposed by Korniyenko et al.). The second paper, in addition to import concentration and the level of extra-EU imports, adds a further requirement at the enterprise level, aimed at measuring the 'granularity' of demand, i.e. by analyzing the number of French companies that import the same product (if a single company imports from a few foreign suppliers, that implies a supply risk). Furthermore, the European Union has initiated several initiatives to identify and address existing and prospective criticalities. The update of the 2020 Industrial Strategy by the European Commission provided an analysis of EU dependencies and strategic capabilities. In particular, the Commission documents contain a bottom-up mapping of dependencies, using a high level of product detail, and an in-depth examination of several strategic technological and industrial sectors, especially related to the dual digital and green transition

(European Commission, 2021 and 2022). In the first phase, the European Commission identifies the products in which the European Union is most dependent on third countries, according to three indicators: the concentration of imports from extra-EU countries as a measure of supply diversification; the share of non-EU markets in total imports, i.e. the importance of extra-EU suppliers; and the weight of extra-EU imports in total European exports, which are a proxy of its production capacity and therefore of its ability to meet import needs in case of supply chain disruptions. In the second step, sensitive ecosystems are identified among these products, i.e. sectors and technological areas of particular interest for European industry. These ecosystems consist mainly of energy-intensity industries (including raw materials, semi-finished products and chemicals), the health sector (including active pharmaceutical ingredients and other health-related products), and inputs and products necessary for the green and digital transformation. Overall, these dependencies amount to 6% of the total EU imports, mainly from China (52%), Vietnam (11%) and Brazil (5%). In terms of processing stages, about 16% of critical products are raw materials, 57% are intermediate goods, and 27% are final products. Finally, the analysis focuses on critical products that represent a real strategic dependency, i.e. that display low potential for the diversification of suppliers, a high concentration in exports and a significant price difference between imports and exports (as a signal of differences in quality or type of product).

Arjona R. et al. (2023) have proposed an update of this approach using the new FIGARO trade data set, which allows consideration of re-exports, unlike most international trade data, which, lacking this information, risk inflating or underestimating the number of products truly at risk of supply interruptions. However, this dataset is suitable only for analyzing the dependencies of the European Union and its member states and cannot be used for international comparisons. Baur and Flach (2022) analyze the German dependencies with China and include among the criteria for identifying critical products their relevance for total production, that is, the risk for the economy as a whole. They focus on intermediate goods and identify three core inputs, using input-output tables, for the final production in the five most important sectors of the German economy (machinery, automobiles, metals, chemicals, and electronics).

This paper contributes to the literature on international trade and global supply chains by focusing on the vulnerabilities in the supply of inputs from abroad at the national level (in addition to those already mentioned, see also, among others, Reiter and Stehrer 2021, who take up and integrate the work of Korniyenko et al., 2017, and Schwellnus et al. 2023). We reconsider and expand the approach proposed by the European Commission to identify critical dependencies (which in turn refers to Bonneau and Nakaa, 2020) in several ways. First, we impose additional criteria specific to the European Union and its member states to qualify critical products more precisely, using the information provided by intra-European trade. This allows the identification of critical extra-EU connections and the role of production linkages within the European Union for each of the EU member states. Thus, we allow the identification of the most critical products within a supply chain, both with and without imports sourced from within the EU, a distinction partially overlooked by the European Commission. On one hand, some supply disruptions can arise within the EU itself, especially because we cannot distinguish exports from re-exports and cannot identify indirect dependencies. On the other hand, to analyze the trade vulnerability of individual member states, it is important to distinguish imports from extra-EU or other EU countries, since EU trade partners are by definition more reliable. Moreover, it is important to distinguish between vulnerabilities at the EU level and those at the member state level, as averages tend to mask country-level heterogeneity. Some countries may be more affected than others by disruptions in the supply chains of strategic inputs that are specific to their production processes and areas of specialization. Similarly, individual member states may pursue different strategies for diversifying their sources of supply, depending on specific ties with non-EU countries—partly because reaching agreements at the EU level can be a lengthy and complex process (e.g., the Mercosur agreement), and the European Union still lacks strong coordination in industrial policy. It is also important to identify which vulnerable products are shared across European countries, as this can offer useful policy insights and help prioritize certain products.

Secondly, we characterize the riskiness of the countries of origin of the critical products, both in terms of their political and climatic characteristics, and we investigate the presence of possible alternative global suppliers to assess the diversification potential of the critical dependencies: two additional criteria absent in the Commission's analysis, which are crucial to identify supply chains from abroad that are at geopolitical risk of disruption and lack of potential alternative sources of diversification. Indeed, we develop a methodology to identify potential alternative suppliers for the same vulnerable products, whereby replacing one country–product pair with another reduces overall supply concentration. This approach maintains the total import value while lowering import dependency, offering insights into how the EU could more evenly redistribute its supplier shares.1

Performing such a progressively selective methodology allows for both a historical, medium-term overview of trade dependencies as well as a policy-focused selection of the most critical products and potential alternative sources. With a clear view of import dependencies, decision-makers can decide where to concentrate efforts to diversify and decouple and where instead to secure already existing trade partnerships or improve and/or develop national production.

The article is divided as follows. The data used are presented in paragraph 2. The methodology is articulated in paragraph 3. The main results for the European Union, the United States, and China are described and analyzed in paragraph 4. Paragraph 5 outlines the conclusions and possible extensions of the analysis.

2. Data

The main dataset used for the analysis is the BACI (Base pour l'Analyse du Commerce International) dataset, provided by the French research center CEPII (Centre d'Etudes Prospectives d'Informations Internationales). BACI contains bilateral trade flows for more than 5,000 products and over 200 countries from 1995 to 2022, at the disaggregation level corresponding to the 6-digit Harmonized System (HS) code, which is the highest level available globally (Gaulier and Zignago, 2010). BACI uses the COMTRADE (Commodities Trade Statistics database) as its sole source of information, which provides data on imports, exports, reimports, and reexports (in value[2] and quantities) at a highly detailed merchandise level (up to 6 digits of the Harmonized System), excluding only flows with values below $1,000 (Berthou and Emlinger, 2011). Compared to COMTRADE, where bilateral trade flows typically differ, depending on the reporting country, and there are many missing values, BACI provides reconciled trade flows, thanks to a harmonization procedure, and accounts for a greater number of countries and periods. Indeed, BACI employs a 'mirror' strategy to impute missing data, leveraging that, in principle, every trade flow should be reported twice, once by the exporting

[1] The European Commission was already considering the potential for diversification for a limited number of dependencies, namely those identified in the sensitive ecosystems. However, to evaluate the diversification potential, only a measure of world export concentration was used; a high level of concentration could indicate that, in the event of an unexpected trade disruption, the EU would have limited capacity for further diversification of imports. Nevertheless, this measure provides no insights into how the EU could redistribute its import quotas across countries, as our methodology does. Additionally, the European Commission was also considering the potential for substitution of imports with domestic production, comparing the average price of exports with the average price of imports. While this information could provide insight on which country-product pairs are the more similar to each other, it does not guarantee that substituting one country-product pair with another one will lower the overall supply concentration level, as our methodology does.

[2] In thousands current USD.

country and once by the importing country. In the case where one of the two is missing, BACI imputes the data based on what is reported by the trading partner. The missing information remains if neither country involved in the commercial exchange has provided any information.

From the BACI data, we obtain a dataset covering 2012-2022, which follows the 2012 HS classification and is compatible with the 5th version of the Classification by Broad Economic Categories, used in the analysis to describe critical dependencies. Additionally, to classify the products according to their geopolitical risk profile, data are kindly provided by SACE (the Italian insurance-financial company specializing in supporting businesses around the world). Finally, several institutional sources (the European Commission, 2021, 2022; International Trade Administration; OECD) are used to identify strategic products, particularly those related to the green transition.

3. Methodology

In this study, a bottom-up approach with a progressively selective methodology is employed, similar to the analysis conducted by the European Commission (2021). This approach aims to identify dependencies as a set of products that progressively meet increasingly stringent criteria. Additionally, some criteria are alternative and aim to ensure both maximum comparability and the highest possible level of detail.

In the first step, two criteria are applied to select and compare critical dependencies at the macro-regional (or country) level. In the second step, intra-area trade flows are also included to better qualify European dependencies and those of individual member countries. In a third phase, to better characterize critical supplies to the industrial sector in EU countries, goods for final consumption and those not critical in recent years are excluded. Additionally, strategic goods and those at high geopolitical or climatic risk are identified. This process allows for the selection of a limited set of critical products that require specific policy measures, as they are simultaneously of great importance to national interests and relatively more at risk.

Once at-risk products are identified, we apply a methodology to find alternative global suppliers to assess the potential for supply diversification for these products.

In what follows, an international comparison applying the first two steps is performed and then the focus is on EU member states.

Two basic criteria are used to select critical dependencies, which can be applied to any country or macro-region: a measure of import diversification and one of substitutability with exports. The following section presents these two criteria with reference to the European Union, but the same reasoning can be applied to any country or area.

i) *Diversification.* Products k are selected if the concentration of extra-EU imports, measured by the Herfindahl-Hirschman index, exceeds a critical value $\overline{I_1}$:

$$I_1^{Eu}(k) = \sum_{i \in Non\ Eu} \left(s(k)_{i,Non\ Eu}^{Eu} \right)^2 = \sum_{i \in Non\ Eu} \left(\frac{m(k)_i^{Eu}}{M(k)_{Non\ Eu}^{Eu}} \right)^2 > \overline{I_1} \qquad [1]$$

Where $m(k)_i^{Eu}$ indicates EU import of product *k* from country *i*, $M(k)_{Non\ Eu}^{Eu}$ is EU total import for the same *k* product from the rest of the world (extra-EU countries), and $s(k)_{i,Non\ Eu}^{Eu}$ indicates the market share of a country i for product k over extra-EU total import.
The critical value $\overline{I_1}$ identifies all products for which imports are concentrated in a few non-EU countries. Specifically, it is set at the 75th percentile level of the global distribution of the trade concentration index by product. In this analysis, the threshold corresponds to a situation where the

import of the product is concentrated in approximately three countries, each representing one-third of the market.

ii) *Substitutability through exports.* We select all the products k that exhibit a significant trade deficit, measured by the normalized extra-EU trade balance:

$$I_2^{Eu}(k) = \frac{m(k)_{Non\,Eu}^{Eu} - x(k)_{Non\,Eu}^{Eu}}{m(k)_{Non\,Eu}^{Eu} + x(k)_{Non\,Eu}^{Eu}} > \overline{I_2} \qquad [2]$$

Where $m(k)$ represents import and $x(k)$ export with respect to the rest of the world (extra-EU). This criterion is equivalent to a threshold set on the ratio between imports and exports $\frac{m}{x}$. The indicator has been employed by other studies on foreign dependencies, and it has the advantage of displaying a symmetric distribution across countries. This facilitates the comparison of the indicator across different countries or regions. The threshold value $\overline{I_2}$ is also fixed at the 75th percentile of the worldwide distribution of the index. Above the threshold, the possibility of substituting imported products with those destined for exports is very limited. Operationally, this criterion selects products for which imports (extra-EU in the case of the European Union) exceed exports by about four times.
The two criteria mimic the "core dependency indicators" chosen in the study by the European Commission (2021), but with modifications made to apply them to other countries and thus allow the comparison of results for the European Union with those for the United States and China. In particular, the first indicator on the concentration of imports is equivalent to the first criterion of the European Commission. The second criterion, on the other hand, is less stringent than the other two criteria proposed by the Commission, which impose conditions, respectively, on total imports and exports of the EU, and therefore also on intra-EU trade.
In the second step, we add a third criterion, specific to the European Union, which considers the possibility of substituting extra-EU imports with products traded among EU countries:

iii) *Substitutability with intra-area flows (between EU countries).* We identify products for which extra-area imports are highly significant compared to intra-area trade:[3]

$$I_3^{Eu}(k) = \frac{m(k)_{Non\,Eu}^{Eu}}{(x(k)_{Eu}^{Eu} + m(k)_{Eu}^{Eu})/2} > \overline{I_3} \qquad [3]$$

Where intra-area trade, from an EU perspective, is the same both from the import and from the export perspective, i.e. $x(k)_{Ue}^{Ue} = m(k)_{Ue}^{Ue}$ (in a balanced dataset as BACI). $\overline{I_3}$ is a threshold calculated on the distribution of the indicator at the EU level; thus, it is the same for all member states.

It is important to note that this criterion, together with the previous one on substitutability with extra-area exports, imposes a set of constraints equivalent to that determined by the two additional conditions in the European Commission's study, which concern the relationship between extra-EU imports and total imports, and extra-EU imports and total exports, respectively. The advantage of our approach is that condition [2] can be applied to all countries (not just the EU area). Condition [3], on the other hand, is the only one that can be applied only to the EU (or to an area comprising more than one country).

[3] It should be noted that this condition is affected by the phenomenon of re-exports, that is, the fact that a portion of the intra-area trade consists of previously imported products from other countries. However, the selection is not biased, because it is based solely on the relative position of the products with respect to the indicator.

3.1. *Industrial dependencies*

To further characterize the dependencies of the European, Italian, French or German industries and to provide policy guidance, the final part of the analysis focuses on capital goods, i.e. investment goods, and intermediate goods, i.e. raw materials and semi-finished products used in production processes, excluding consumer goods. The substitutability between intermediate inputs is on average more difficult (Fujiy, B. C. et al., 2022), especially in the short term, and can lead to a multiplier effect of shocks throughout the entire production chain (Atalay, 2017). To make the results more robust and avoid capturing the effect of occasional or outdated dependencies (Vicard and Wibaux, 2023), the analysis also excludes products that are no longer critical after 2016 or that, between 2017 and 2022, are not critical most of the time (three years out of five). However, all products that fall under the classification of strategic dependencies published in 2021 by the European Commission (European Commission, 2021) are included.

We also consider two additional selection criteria: the strategic nature of the products, based on the evaluation of different institutional sources, and the geopolitical and climate risks associated with the supplier countries, according to indicators developed by SACE, the Italian insurance-financial company specializing in supporting businesses that export and grow in foreign markets.

Strategic products

The analysis of the value and number of products that constitute critical dependencies of a country is not sufficient to fully assess its vulnerability to potential supply disruptions from abroad. Not all products are equally valuable: some are considered indispensable for ensuring national security and health protection, or crucial for industrial growth and competitiveness, e.g. intermediate or capital goods required for the green and digital transitions. Conversely, a lower strategic dimension allows us to classify some critical industrial supplies, for example in the agri-food and textile industries, as relatively less central, if they don't represent a strategic risk for the industrial growth potential or for health and safety.

We analyze strategic dependencies, critical for different stages of production and supply chains, thus including, beyond raw materials, also semi-finished products and investment goods, by exploiting various institutional sources: the lists of strategic products provided by the European Commission (2021, 2022)[4], the critical supply chains selected by the International Trade Administration (ITA, an agency of the United States Department of Commerce that promotes exports of U.S. non-agricultural goods and services[5]) and the roster of raw materials critical for the green transition by the Organization for Economic Co-operation and Development (Kowalski, P., & Legendre, C., 2023).

Combining these three sources, we identify the following categories of strategic products: minerals, metals, and other critical raw materials; drugs and active ingredients; chemical products; fossil fuels; wood; and others (not classifiable in the previous categories). Furthermore, using both ITA and OECD classifications, we pinpoint the strategic products most involved in the energy transition:

[4] The European Commission was already considering the strategic aspect of critical dependencies in 2021 (European Commission, 2021); "[…] the bottom-up mapping of dependencies […] will focus on a number of these more sensitive ecosystems […] when considering the question of identifying possible strategic dependencies. This also follows the Council conclusions of 16 November 2020, which specifically highlighted health, defense, space, digital, energy and critical raw materials as examples of sensitive industrial ecosystems and areas.[…]"

[5] https://www.trade.gov/data-visualization/draft-list-critical-supply-chains.

products used in the production of batteries, fuel cells, renewable energy, or for carbon footprint reduction.

Products at geopolitical and climate risk

Another dimension that is crucial to consider is the geoeconomic risk associated with the countries of origin of critical products, which may compromise the regular supply from those countries.

We consider two types of geoeconomic risk, i.e. political and climate risks. The former refers to the risk of political instability, acts of violence, fragility of the judicial regulatory framework, and so on. The latter measures the probability of extreme natural events that may hinder production or shipping.

To quantify these risks, we enrich our analysis with SACE risk indicators. A measure of the likelihood of political violence or war and expropriation and nationalization is used to characterize the risk profile from the political side. The climate change risk indicator, developed by SACE in collaboration with the Enel Foundation, assesses how likely natural events are that can disrupt supply chains. Specifically, the political (or climate) risk associated with a given critical product is defined as the weighted average of the supplier countries' political (climate) risks, with weights proportional to the value of imports of the product from each country.

Substitutability with extra-EU imports

The analysis of vulnerabilities is based on a snapshot of critical dependencies, focusing on products whose imports are highly concentrated among a few foreign suppliers, and which cannot easily be alternatively sourced. This allows for the identification of products at higher risk of supply disruption since an idiosyncratic shock in a specific foreign market could lead to an actual shortage of intermediates or production capacity, due to the lack of alternative suppliers, among those already present in a country's market.

However, there may be other relevant global suppliers from whom imports of the country are little or none.[6] As a first step, the distribution of a country's imports can be compared with the global distribution of exports for the same product, to verify whether there is scope to further diversify imports of the product. It is possible, in principle, to reduce the share held by the main exporters to the country in favor of other global suppliers that are relatively less present or absent in the country, thus increasing the pool of potential supplier countries and reducing the risk of supply chain disruptions.

To this end, we construct an iterative algorithm that minimizes the concentration of imports, starting from the initial distribution for the reference area, under the constraint that the shares of potential suppliers cannot exceed their shares at the global level (i.e. as global exporters). In other words, it solves the following constrained minimization problem:

$$Min_{\tilde{s}_i} \sum_{i \in Non\,Eu} \left(\tilde{s}(k)^{Eu}_{i,Non\,Eu}\right)^2 \quad s.t. \qquad [4]$$
$$\tilde{s}(k)^{Eu}_{i,Non\,Eu} \leq Max\left(s(k)^{Eu}_{i,Non\,Eu} \,;\, s(k)^{Wo}_{i} \right), \quad \forall\, i \in Non\,Eu$$

[6] We assume that the available level of disaggregation (6-digit HS codes) is sufficient to ensure that same-code products, exported from different countries, are close to perfect substitutes. However, significant differences in quality or price may exist among different suppliers, despite sharing the same product code.

Where the objective function is equal to the first criterium $I_1^{Eu}(k)$, that is Herfindahl-Hirschman index of EU imports of a product k, and $s(k)_i^{Wo}$ is defined as a country i share of product k in global trade.

The algorithm effectively produces the most uniformly distributed import distribution (given the constraint). Once the potential "most uniform distribution" has been constructed, it is possible to calculate the concentration index of this hypothetical distribution and determine which critical products fall below the concentration threshold.

4. Results

In this section, we briefly present the results of the analysis, highlighting its main takeaways. For additional details on the results obtained for each area/country, please refer to the appendix. Firstly, we compare the critical dependencies of the European Union to the ones of its main trading partners, the U.S. and China, through the criteria [1] and [2] detailed in section 3. Secondly, we compare the results for three large EU member states, Germany, France, and Italy, also in comparison with the European average, adding the criterion [3]. For each comparison, we characterize the critical products selected by their share in total imports, in terms of value and frequency (number of products), and we analyze their variability over time. We further investigate if trade dependencies show any trend over time, and we evaluate which constraints described in the methodological section were most binding. Furthermore, we analyze the main areas of origin of critical dependencies, the type of products[7] and the supply chains[8] that are most affected by the vulnerabilities. Thirdly, we select and describe *industrial* dependencies; here we report detailed results concerning only those common to all the European countries analyzed. For these industrial critical products, we evaluate their strategic nature, the geopolitical risk associated with the suppliers, and the potential substitutability with other supplier countries outside the European Union. Finally, we provide some insights on why certain products may be deemed critical for the EU on average, but not for individual member countries, and the other way around. Table 1 summarizes the prominent characteristics of the products selected as critical dependencies (applying the first *two* criteria detailed in the methodology section) for the EU, U.S., and China. Comparing the dependencies across countries, important considerations can be drawn:

- Foreign dependencies are a rather long-standing structural phenomenon, indicative of a geographical specialization in certain sectors or products. While overall stable as a percentage of total imports, dependencies do show variation over time regarding the geographical origin and the composition of critical products.
- The EU and the U.S. dependencies show an increase during the pandemic, but not those of China.

[7] According to the 5th version of the Classification by Broad Economic Categories (BEC rev.5), products can be distinguished, by end-use, into intermediate consumption (generic or specific), gross fixed capital formation, and final consumption.

[8] In particular, in BEC rev. 5 we can distinguish 8 different supply chains: 1) Agriculture, forestry, fishing, food, beverages, tobacco; 2) Mining, quarrying, refinery, fuels, chemicals, electricity, water, waste treatment (called for the present analysis 'Commodities'); 3) Construction, wood, glass, stone, basic metals, housing, electrical appliances, furniture; 4) Textile, apparel, shoes, jewelry, leather; 5) Transport equipment and services, travel, postal services; 6) ICT, media, computers, business and financial services; 7) Health, pharmaceuticals, education, cultural, sport; 8) Government, military and other. See United Nations. "Classification by Broad Economic Categories." (2002) for more details.

- The U.S. dependencies are primarily the result of a negative trade balance, which only partly penalizes the European Union and China; they also show the lowest import diversification.
- Critical products are in general concentrated in different sectors or suppliers than total imports, thus dependencies are not proportionally represented in international trade but exhibit unique and specific characteristics. China, although it is an important trade partner of both the EU and the U.S., is always over-represented as a sourcing country among critical products with respect to the overall imports' value. Similarly, the ICT supply chain weighs relatively little in total European and American imports (around 10%) but it counts for 30-40% of dependencies.

	EU	U.S.	CHINA
Levels (as % of total imports) & trends[9]	8% of products, 10% in value. Stable until 2019, then almost 10 p.p. growth in value, mainly due to energy products.	17% of products, 21% in value. Relatively stable until 2019, then almost 5 p.p. growth in value in 2020, partially recovered in 2022.	9% of products, 17% in value. Floating around 20%, with a decrease (in value) of about 5 p.p. between 2015 and 2018, and growing again up to 20% from 2020.
Volatility[10]	≃20% of the critical products enter or exit the sample every year		
Tightness of constraints - [1] Diversification	≃ 39% of imported products show an HHI index > the threshold.	≃50%	≃45%
- [2] Substitutability through exports	About 15% of imported products display import/export ratio > the threshold.	≃ 30%	≃14%
Geographical origin[7]	≃ 45% are from China. For the European Union, this corresponds to a high level of total imports from China (about 20%); for the United States China covers only about 15%-20% of total products, while Canada and Mexico rank first with a 27% share		≃25% from Oceania, while in total imports it counts only for 6%; the greatest share comes from other developed Asian countries (about 25%)
Type[7]	55-60% consumption goods (the most relevant in total imports too – 30%)		50% intermediates goods (the most relevant in total imports too – 60%)
Supply chain involved[7]	≃ 40% ICT, while in total imports it represents about 10%; a quarter of products belong to raw materials, chemical and energy supply chain	≃30% ICT and 25% in Construction, while in total imports they represent respectively about 10% and 20%	More than 40% are Commodities (very relevant in total imports too – 35%), and 30% are Agri-Food related (10% in total imports)

Table 1 - European dependencies compared with those of the United States and China

[9] See Appendix A or B for additional details on the results for each area/country.
[10] As detailed in Vicard and Wibaux (2023), when trade vulnerabilities are identified following the European Commission methodology, they vary heavily from one year to the next. Thus, we report here the volatility associated with our methodology.

Table 2 summarizes the main features of the products selected as critical dependencies for some of the EU member countries (applying the first *three* criteria detailed in the methodology section). When dependencies are compared, some key takeaways emerge:

- When intra-EU dependencies are taken into account, the overall level of critical dependencies for the European Union decreases, although not drastically in absolute terms. The single market can serve as a tool to diversify the supply sources of member states, also because the European Union as a whole has greater capacity to engage in trade with a wider range of partners due to its size (even though this may conceal indirect dependencies). However, as noted by the IMF (2024), significant obstacles to the exchange of goods and services within the Union persist. If existing trade barriers were removed, intra-EU trade would benefit accordingly.
- Dependence represents a similar share of total imports across European countries. However, while on average critical imports have increased in the last two years, Italy and France show a decrease in dependencies since 2020. In France, this is due to a substantial trade balance improvement and a shift in trade towards other EU countries, while in Italy it is due to a rearrangement of critical products' composition, e.g. a decrease in the share represented by energy products.
- Italy, France, and Germany show similar import concentration values, as well as trade balance and substitution with intra-EU trade, while the EU on average displays much lower import concentration and a lower import/export ratio.
- Critical imports tend to be concentrated in the same countries that are the most relevant for total imports; however, China is by far the most relevant area, representing the origin of about half of EU critical imports, approximately 2.5 times the share held for total imports. Italian imports are more diversified than those of other EU countries.
- Consumption goods are by far the most important category in both critical and total imports. ICT goods and commodities are strongly over-represented as critical products.
- In the EU, energy products represent an important share of total imports (about 35%) but show up in critical imports only in 2021-22 (30-40% of critical import value, mostly natural gas imported from other non-EU European countries). In Italy, energy products represent about 30% of critical imports' value and about 35% of total imports value on average over the entire period analyzed (with the large majority being natural gas except for 2022). In France, energy products represent about 30% of total import value but show up in critical imports only in 2022. In Germany, energy products represent over 2012-22 about 20% of critical imports' value and about 20-30% of total imports value.
- Italy and Germany are both among the EU countries most dependent on extra-EU energy inputs. However, from 2019 to 2022, Italy kept almost the same number of supplier countries, but increased the gas import quotas from Africa, Middle East and non-EU European countries – e.g. Norway, Bosnia and Montenegro (areas previously under exploited)- thus decreasing the gas imports concentration. On the contrary, Germany reduced the number of gas suppliers, while noticeably increasing natural gas imports from Norway.

	EU (intra-area trade included)	ITALY	FRANCE	GERMANY
Levels (as % of total imports) & trends[7]	6,5% of products, 9% in value. Stable up to 2020, then + 5 p.p., mainly due to energy products.	9% of products, 11% in value. Relatively stable in 2013-19, then - 5 p.p. (energy products, especially gas).	10% of products, 15% in value. Relatively stable in 2013-19, then - 5 p.p. (less imports in computers and more imports from EU).	9% of products, 13% in value. Relatively stable in 2013-19, then + 10 p.p. (energy products, especially gas, and ICT, especially electronic equipment from China).
Volatility	About 20-30% of the critical products enter or exit the sample every year			
Tightness of constraints - [1] Diversification	≃38% of imported products show an HHI index > the threshold	≃60%	≃58%	≃54%
- [2]Substitutability through exports	≃15% of imported products show an import/export ratio > the threshold	≃20%	≃24%	≃23%
- [3]Substitutability with flows from intra-area EU	≃25% of imported products show an import/export ratio > the threshold	≃24%	≃26%	≃29%
Geographical origin[7]	≃50% from China (≃20% in total imports).	Import, both critical and total, is quite diversified	30-40% from China, 50% from extra EU in 2022 (both ≃20% in tot. import).	40% from China and, in 2022, from Europe extra EU (both ≃25% in tot. import).
Type[7]	50-70% are consumption goods, which in total imports represent only about 30-35%.			
Supply chain involved[7]	40% ICT and Commodities (10% in tot. imports).	40% Commodities (≃ 35% in tot. import)	25% ICT until 2019 (25%), then Agri-food (27%) and Commodities (47%).	30% ICT and 25-30% Commodities (≃ 15% and 20% in tot. imports respectively).

Table 2 - EU member states dependencies

Finally, Figure 1 and Table 3 display some key characteristics of the European *industrial* dependencies, i.e. of those investment and intermediate goods repeatedly critical in the last five years (from 2017), which are mostly imported from extra-EU countries and for which the supply is heavily concentrated and difficult to replace with internal resources or flows from other European countries.

Figure 1 highlights how many products are selected for each of the EU members analyzed (in black) and how the selection overlaps across countries and the EU. Italy is the EU member state that shows the greatest number of industrial dependencies (378), about half of which are neither shared with the other EU countries analyzed nor with the EU on average.[11] France follows closely (315), with about 63% of selected products shared with the other EU countries. Finally, Germany ranks third for the number of products selected as industrial dependencies (283), 70% of which are in common with the other EU countries.

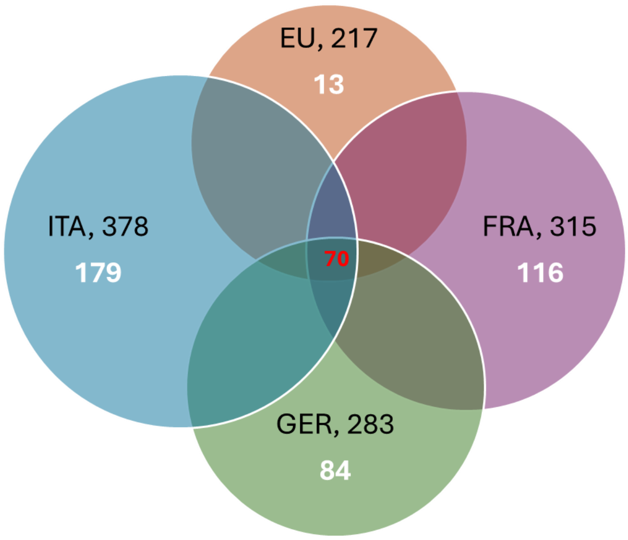

Figure 1 – EU Industrial Dependencies

Note: in black is the total number of *industrial* critical products, in white is the number of products which exclusively belong to one country, and in red is the number of critical products shared by all three countries and the EU on average. The size of the circle is proportional to the number of products selected as industrial dependencies.

As Figure 1 points out, not all European dependencies are critical for the single EU member states, and vice versa. Why such a mismatch? Taking the comparison between Italy and the EU as an illustrative case we note that:

a) Almost 60% of Italian dependencies are not identified as critical products for the EU as a whole (238 products); out of these, 49 are excluded because they are critical for less than three over five years; in the remaining cases (189), where at least one of the 3 criteria detailed in section

[11] See Centro Studi Confindustria, (2023). Catene Di Fornitura Tra Nuova globalizzazione e autonomia strategica, for additional details on Italian dependencies.

3 is not met at the EU level, the year/product combination is excluded from EU dependencies because:

- in 55% of cases, the diversification constraint is not binding.
- in 74% of cases, the substitutability through exports constraint is not binding.
- in 57% of cases, the substitutability with flows from intra-area countries constraint is not binding.

One may reasonably expect that a member state country would be more trade dependent than the EU on average, if only because of its size, is expected to be able to diversify more. Indeed, in almost 60% of the product-year combinations that are not selected, the EU suppliers are less concentrated. Also, there are many cases in which the EU is more able to substitute imports with exports, or with intra-EU trade. In most (almost ¾) of the cases Italian industrial dependencies are not critical at the EU level because the European trade balance is higher than the threshold. The results suggest that the Single Market has the potential to increase the resiliency of the Italian industry, through resources that are currently exported abroad (extra-EU) or in other EU countries (intra-area flows).

b) Almost 40% of European dependencies are not identified as critical products for Italy (73 products); out of these, 21 are excluded because they are critical for less than three over five years; in the remaining cases (52), where at least one of the 3 criteria detailed in section 3 is not met at the Italian level, the year/product combination is excluded from Italian dependencies because:

- in 24% of cases, the diversification constraint is not binding.
- in 76% of cases, the substitutability through export constraints is not binding.
- in 66% the substitutability with flows from intra-area countries constraint is not binding.

The number of products critical at the EU level but not at the Italian level is significantly lower than in the opposite direction, as expected. Still, there are several explanations for why this may be observed. Firstly, it may be the case that some of those products are critical for another EU member state. Moreover, in most of the cases, the Italian trade balance indicator is not binding, that is the Italian exports seem able to substitute for lower imports. Secondly, there is a minority of cases in which Italy can diversify its suppliers more than the *average* of the EU member states, implying that some other countries are suffering from higher import concentration for a specific combination of products. Even if this may seem counterintuitive, we must consider that the distribution of imports, at the product level, can be very heterogeneous and volatile.

Finally, it is important to stress that two-thirds of EU critical products that are not critical for Italy don't meet the third criterion, that is the Italian industry has enough resources coming from intra-EU imports. This may be detected, however, as an *indirect* dependency: dependencies of another EU member from extra EU imports. The task of detecting these cases is left for future research.

Finally, for the sake of brevity, we focus our attention on the industrial dependencies shared between the EU as a whole and the three EU member states analyzed only. Being critical dependencies for three of the most important EU manufacturers, such products are of particular interest and can represent a potential target for EU industrial policies. Table 3 reports their key features.

	In common with the EU, Italy, France, and Germany
Geographical origin	China (78% of critical import value and 33% of critical products)
Type	Capital goods (68% of critical import value), specific intermediates goods (46% of critical products)
Supply chain involved	ICT (64% of critical import value), Commodities (41% of critical products)
Strategic	46 products, 90% of critical import value; 16 are raw materials (mainly mineral and chemical rubber plastic products)
At geopolitical risk	43 products, 85,5% of critical import value
Substitutability with other extra EU trade partners	-20 p.p. in HH index on average; -24p.p. in HH average index of Construction and Agri-Food and -21p.p. in HH average index of Commodities

A significant share of the EU's critical imports originates from China, which accounts for 78% of the total critical import value and is the source of 33% of critical products. These imports are predominantly composed of capital goods (68% of critical import value) and specific intermediate goods (46% of critical products). The most affected supply chains include Information and Communication Technology (ICT), which represents 64% of the critical import value, and commodities, covering 41% of critical products. Among the 46 identified strategic products—representing 90% of the total critical import value—16 are raw materials, primarily in the form of mineral, chemical, rubber, and plastic products. Additionally, 43 of these products (equivalent to 85.5% of the critical import value) are considered to be exposed to geopolitical risk. Further analysis of these latter products reveals a strong geographic concentration, with China alone accounting for 19 of these products—nearly 44% of the total. Beyond China, several other suppliers of risk-exposed products are located in regions characterized by political instability, weak institutional frameworks, or elevated geopolitical tensions. These include India (6 products) and Russia (4 products), Turkey (3 products), Pakistan (2), Ukraine (1), a number of African nations—Egypt, Congo, Guinea, Nigeria, South Africa, and Morocco— and Argentina and the Philippines, each responsible for one product. Figure 2 illustrates the positioning of each of the listed countries in terms of political and climate risk, based on SACE indicators, along with the average of the two indicators across all countries supplying critical inputs (indicated by the orange lines).

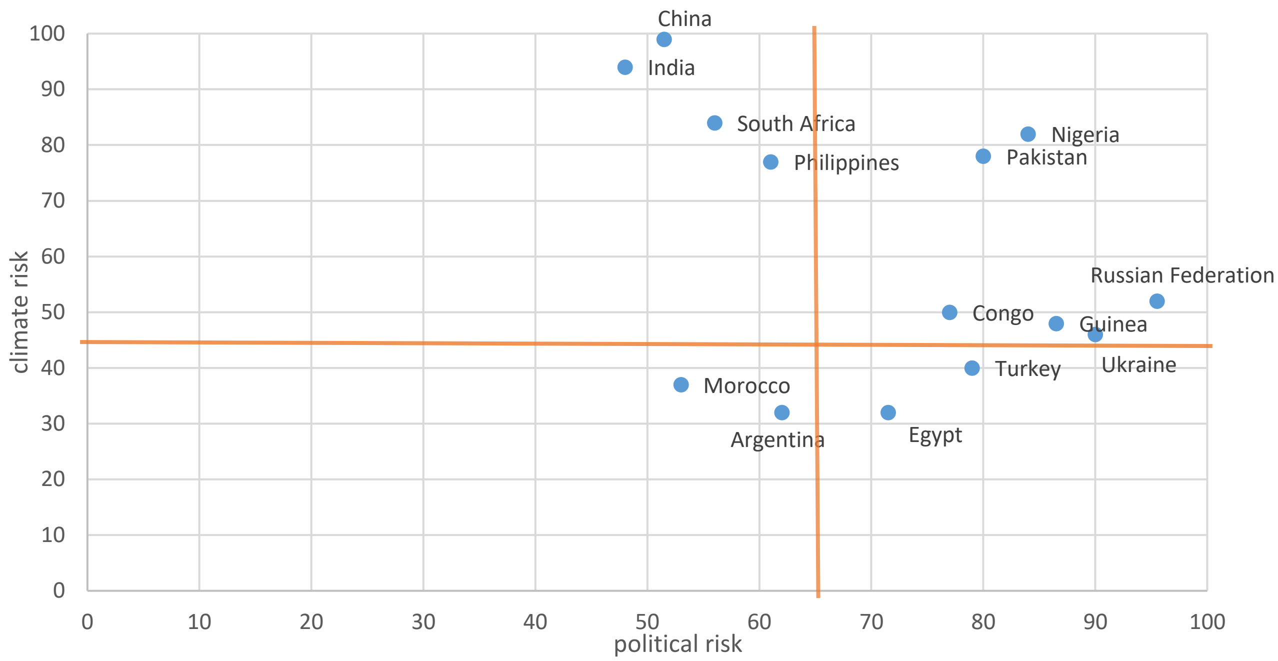

Figure 2 – Climate and political risk distribution of EU suppliers of 43 products at high political or climate risk

Furthermore, we examine the substitutability of vulnerable products with alternative non-EU suppliers. To assess the potential for import diversification, we compare a country's current import distribution with the global export distribution for the same product, identifying underutilized or untapped global suppliers. In principle, reducing reliance on dominant suppliers in favor of less-represented global exporters can expand the pool of sourcing countries and mitigate supply chain risks. To operationalize this, we develop an iterative algorithm that minimizes import concentration by reallocating shares—within the constraint that no supplier's share exceeds its global export share (see Equation [4]). The algorithm yields the most uniform feasible distribution of imports, from which we compute a hypothetical concentration index. This allows us to identify which critical products could fall below a vulnerability threshold under an optimally diversified sourcing scenario. For example, figure 3 and 4 illustrate the import share distribution of two strategic raw materials—quartzite and antimony—before and after applying the algorithm. These maps show both the current supplier distribution and the reallocated distribution derived to achieve the most diversified sourcing scenario possible.

In the case of quartzite (figure 3), current EU imports are highly concentrated in Brazil, which accounts for 86.6% of total Union imports. Other suppliers include Norway (6%), Ukraine (2.5%), Angola (1.6%), India (1.4%), China (1.2%), and the USA (0.3%), along with a number of smaller exporters. All countries shown in grey have a zero import share. By applying our algorithm, Brazil's dominant share is significantly reduced—from 86.6% to 24%—and redistributed among both existing EU trade partners (e.g., China's share rises to 13.2%, and the USA's to 1%) and new potential suppliers. As a result, a greater number of countries are represented in light blue on the map, reflecting their inclusion in the diversified sourcing scenario, even if their individual shares remain modest. The overall HH index decreases, from 0.75 to 0.13.

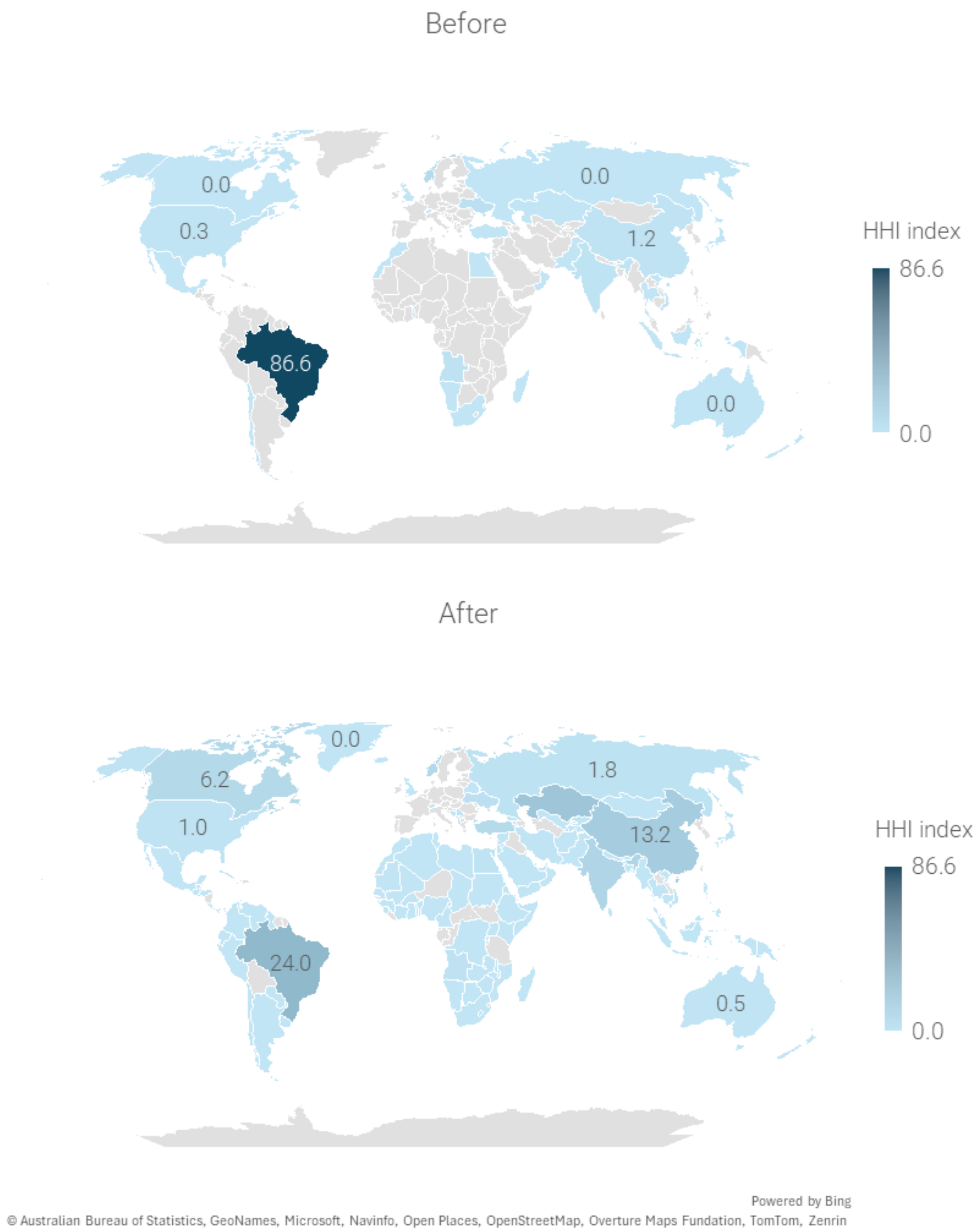

Figure 3 – Import share distribution before and after the algorithm to minimize concentration, quartzite (HTS 250620)

In the case of antimony (Figure 4), current EU imports are heavily concentrated in Turkey, which supplies 68% of the total, followed by Tajikistan (12.7%), Bolivia (11%), South Africa (3.9%), China (1.6%), Guatemala (1%), and several minor suppliers. After applying the algorithm, Turkey's share is substantially reduced to 14.4%, with redistribution toward both existing suppliers—such as Tajikistan, whose share increases to 14.2%—and new potential suppliers. Notably, countries not currently exporting antimony to the EU but present in global export markets, such as Australia (which would reach a 14.4% share), are included in the reallocation. This expanded supplier base illustrates the potential for significantly lowering concentration (HHI decreased from 0.49 to 0.11) and enhancing supply resilience through diversification.

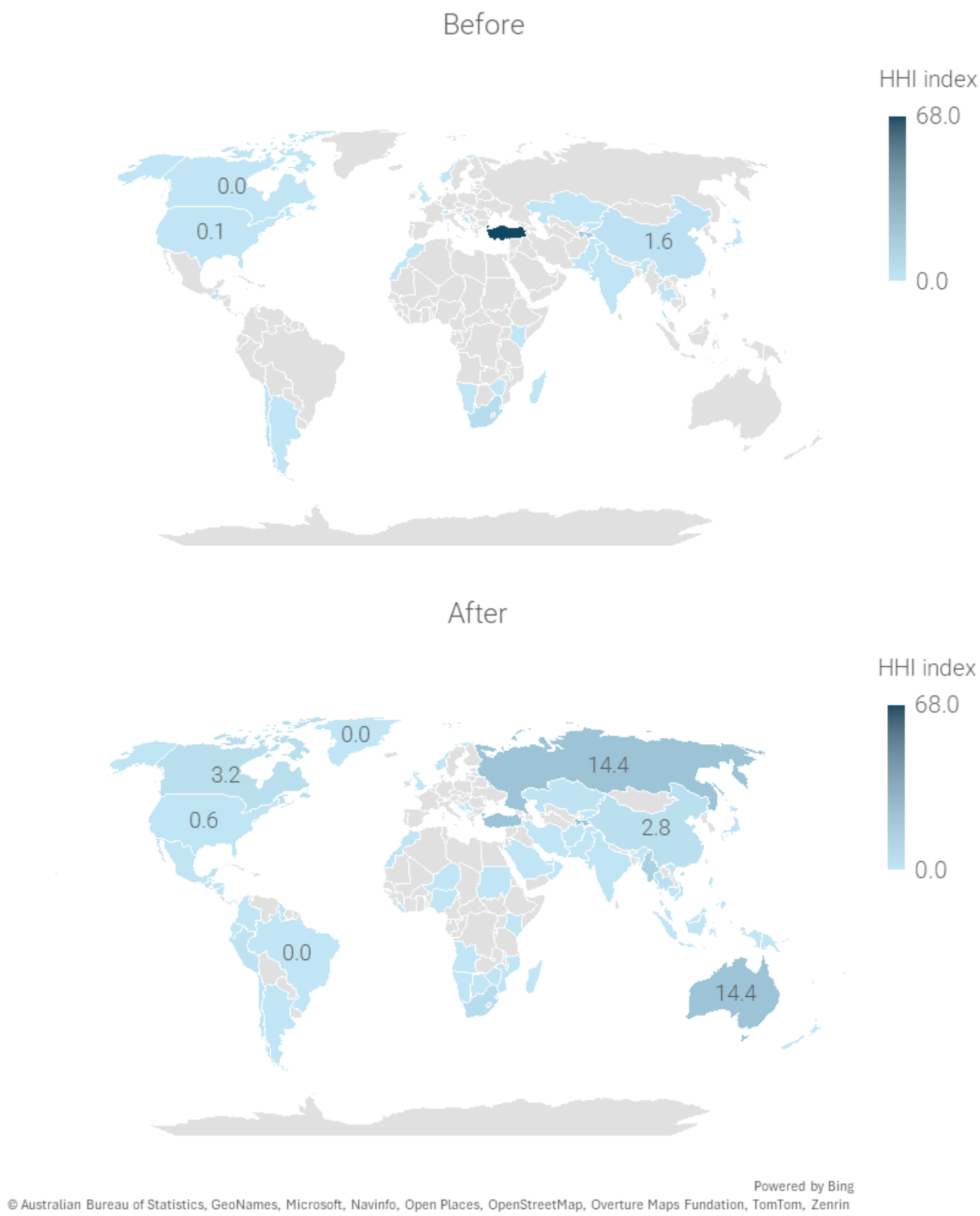

Figure 4 – Import share distribution before and after the algorithm to minimize concentration, antimony ores and concentrates (HTS 261710)

5. Discussion and conclusions

The international fragmentation of production leads to a tight integration between countries and sectors, which transmits and, in some cases, amplifies the impact of shocks upstream and downstream in supply chains. This occurs because intermediate inputs (which account for more than half of international trade) are complementary and, therefore, challenging to substitute in producing final goods and services, especially in the short term. Recently, the focus has been on the impact of bottlenecks upstream in global value chains, particularly in China, across all sectors and countries downstream. According to a recent OECD study, greater dependence on international supply chains has been associated with poorer sector and country performance because of upstream bottlenecks during the COVID-19 pandemic; this impact doubles when supplies are concentrated in a few markets or firms (Schwellnus C. et al., 2023).

Our work expands the analysis of the European Commission (2021) by identifying critical dependencies or vulnerabilities of EU countries on foreign suppliers, compared to those of the United States and China. The selection criteria for critical products include geographic diversification of imports, substitutability with exports, and, for European countries, substitutability with intra-area trade. Import concentration is the most binding of all the criteria, i.e., it selects the largest share of products. In addition, differences emerge in countries' ability to diversify imports' country of origin, both at the global level and between EU member states and concerning the capacity to substitute imports with exports.

In general, global trade tends to be relatively concentrated. Critical dependencies result from long-term choices involving specialization, reallocation of international production chains, and efficiency-seeking in trade partner selection. For Europe (and the U.S.), this process is closely tied to the industrial growth of emerging countries, with China at the forefront.

As a novelty compared to the existing literature, by focusing on intermediate and capital goods, this work characterizes industrial vulnerability also according to the riskiness of the countries of origin of critical products, both in terms of their political and climatic characteristics, and investigates the presence of possible alternative global suppliers, to assess the diversification potential of the critical dependencies. It simulates the possibility of greater diversification, decreasing the share held by the major exporters in a country in favor of those less present in order to increase the pool of potential suppliers and reduce the risk of supply chain disruption. By exploiting "potential" suppliers, the concentration of the critical imports shared by Italy, France, and Germany could decrease by 20 percentage points.

The analysis is subject to certain limitations. Firstly, the methodology is based on import data and does not include data on production capacity for each country (Arjona R et al., 2023); however, integrating the data with information on domestic production would neither allow for an analysis of vulnerabilities at a high level of detail nor a comparative analysis at the international level. Another limitation lies in the inability to isolate secondary or higher-level supply linkages in these data, which, on one hand, poses a risk of both overestimation and underestimation of some dependencies and, on the other hand, prevents the identification of indirect vulnerabilities that are not immediately visible. An important element for further exploration is to evaluate the quality of the proposed methodology, assessing its sensitivity to the thresholds used in the selection criteria proposed and ideally comparing the set of dependencies obtained with a confirmed case of supply shortage, for example, during the COVID-19 pandemic peak.

Our analysis offers, nonetheless, a useful tool for investigating critical and strategic dependencies and the availability of alternative resources, allowing for the design of informed industrial and commercial policies with both quantitative and qualitative data. Decoupling is neither likely nor desirable; it can only be selective and depends primarily on economic and technological factors. However, there is room to reduce dependencies. Identifying ex ante vulnerabilities related to structural dependencies with high supply disruption risks can help policymakers select which products to target. Investments in national and European production capacity, diversification of trade, and industrial partners (e.g. reinforcing existing trade agreements) are necessary to increase the resilience of supply chains to global shocks caused by natural disasters or commercial and political conflicts and to lead the green and digital transition of the global industry.

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Appendix

A) EU, U.S. and China critical import

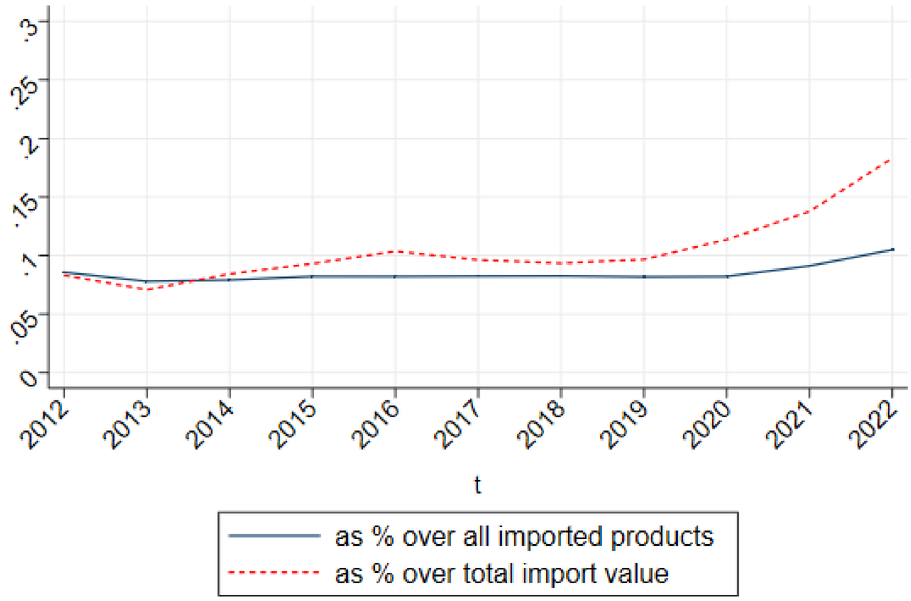

Table A.1- EU critical imports (% over total imports)

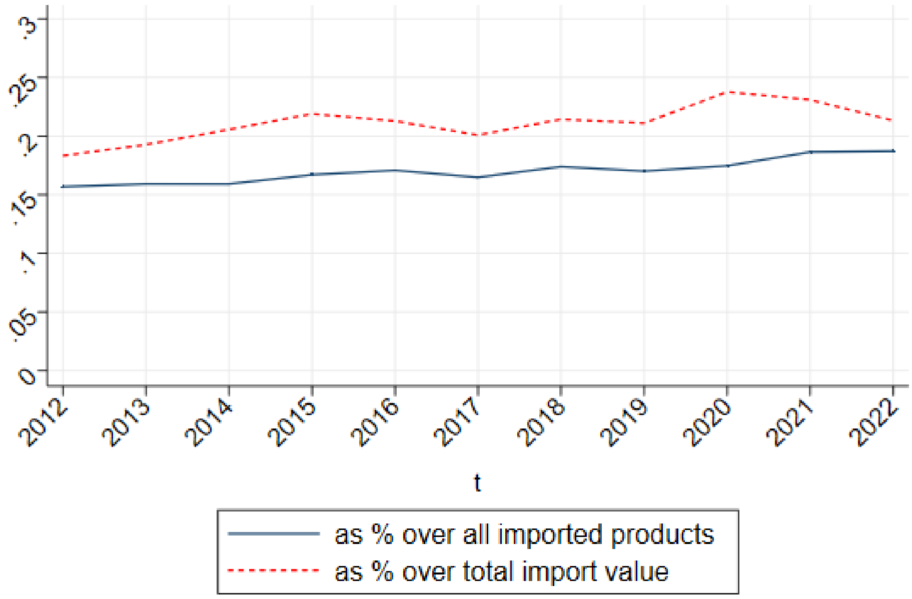

Table A.2- U.S critical imports (% over total imports)

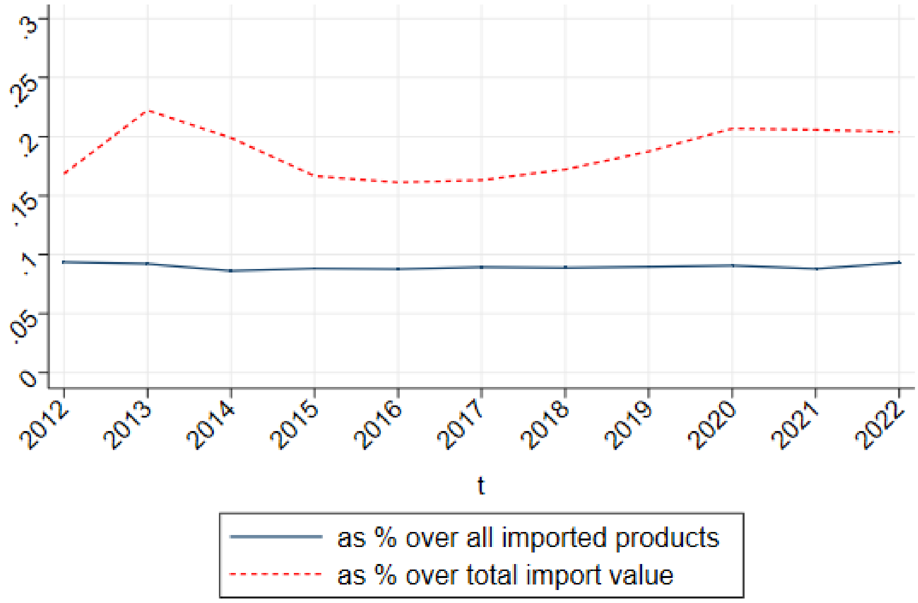

Table A.3- China critical imports (% over total imports)

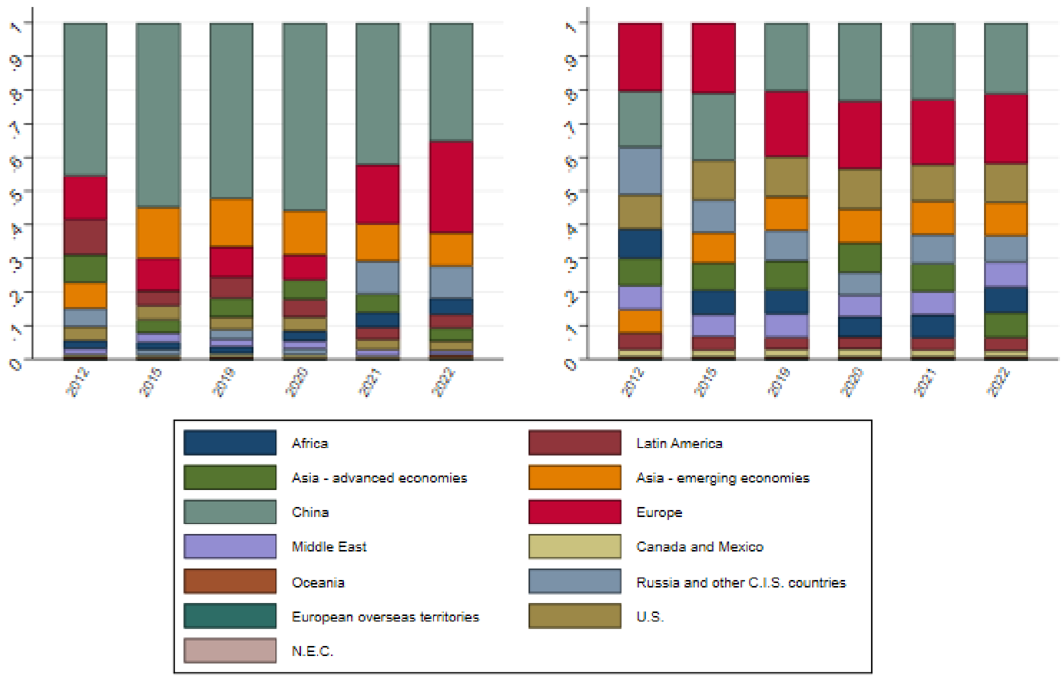

Table A.4- EU critical imports share by area (left panel - % over total critical import value; right panel - % over total import value)

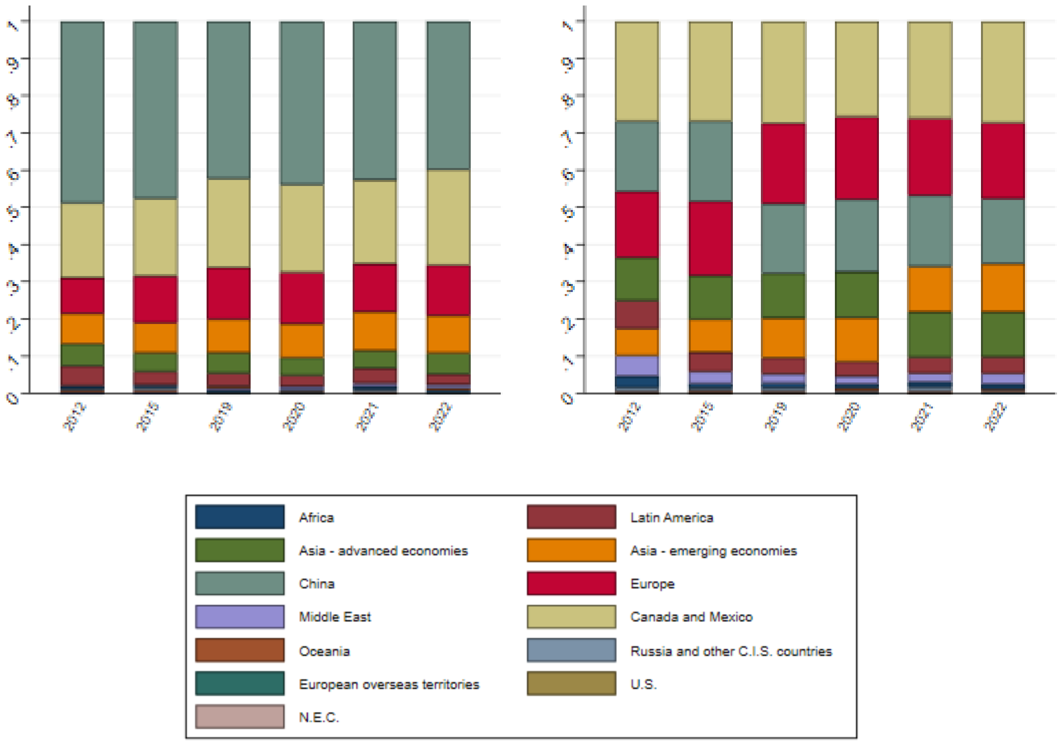

Table A.5- U.S critical imports share by area (left panel - % over total critical import value; right panel - % over total import value)

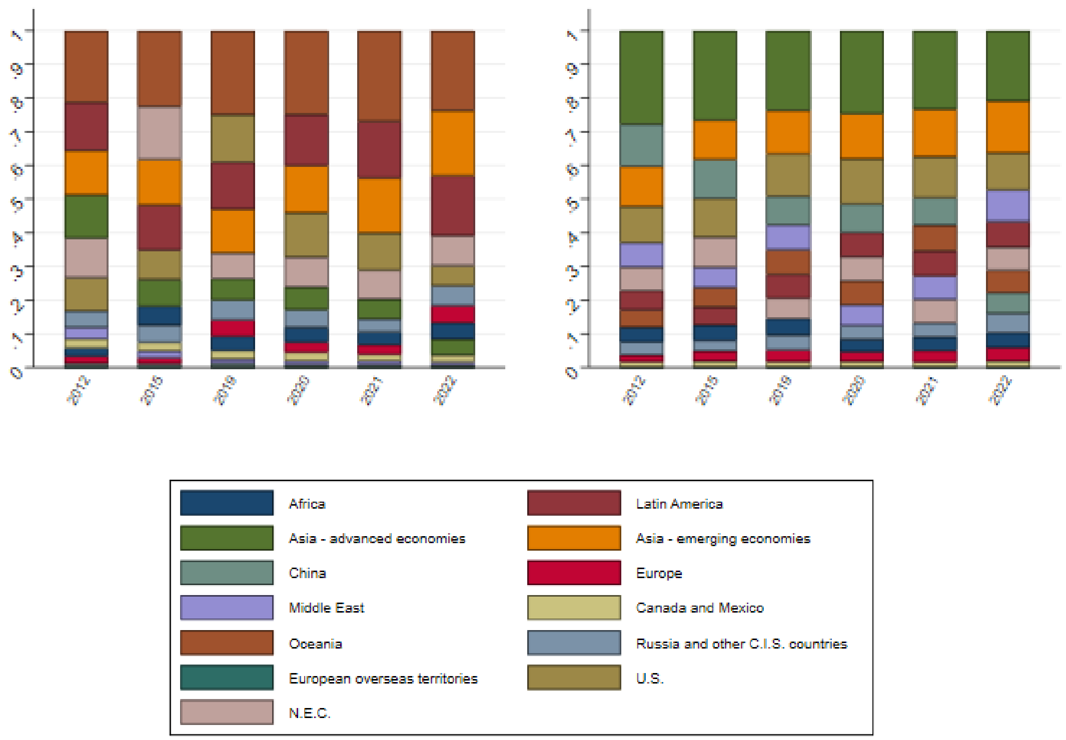

Table A.6- China critical imports share by area (left panel - % over total critical import value; right panel - % over total import value)

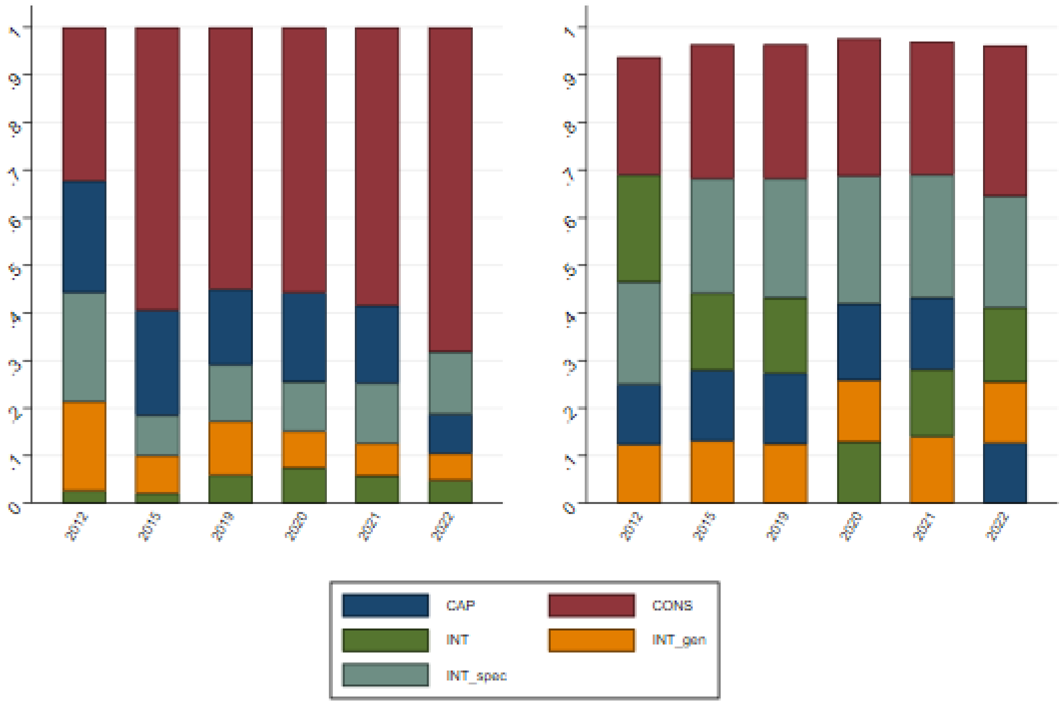

Table A.7- EU critical imports share by end-use (left panel - % over total critical import value; right panel - % over total import value)

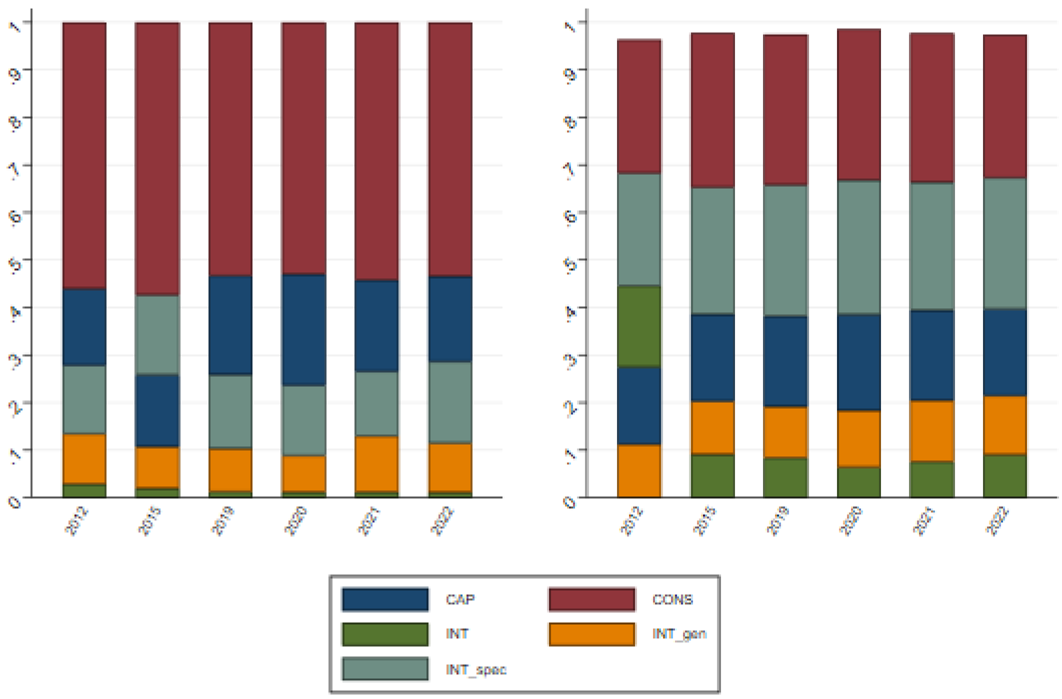

Table A.8- U.S. critical imports share by end-use (left panel - % over total critical import value; right panel - % over total import value)

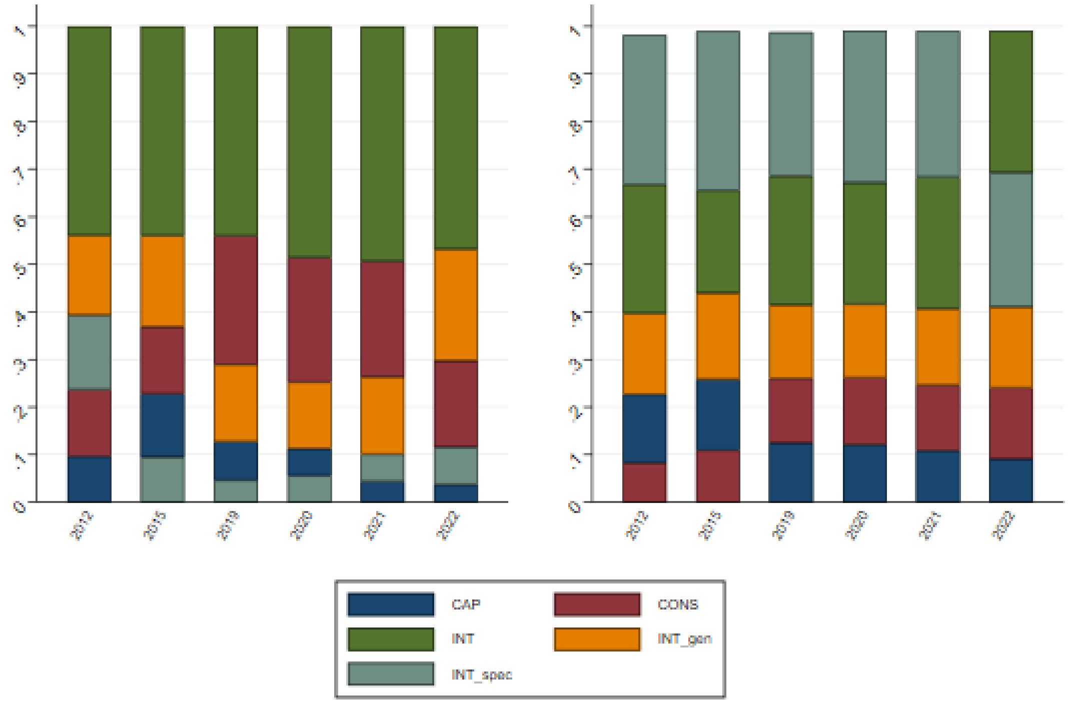

Table A.9- China critical imports share by end-use (left panel - % over total critical import value; right panel - % over total import value)

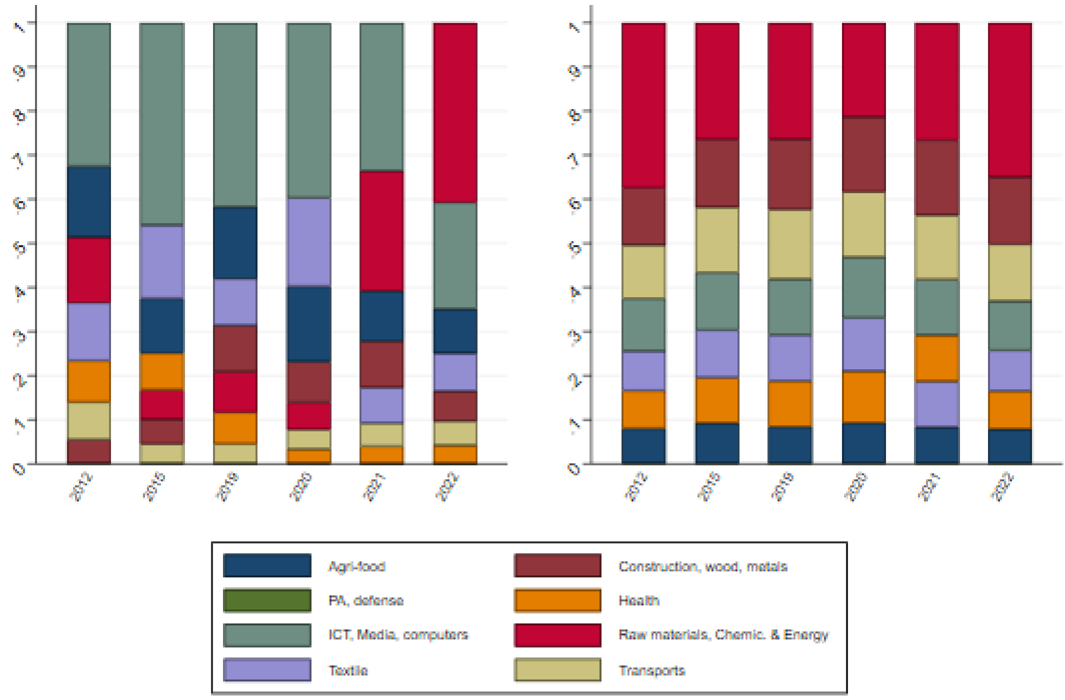

Table A.10- EU critical imports share by supply chain (left panel - % over total critical import value; right panel - % over total import value)

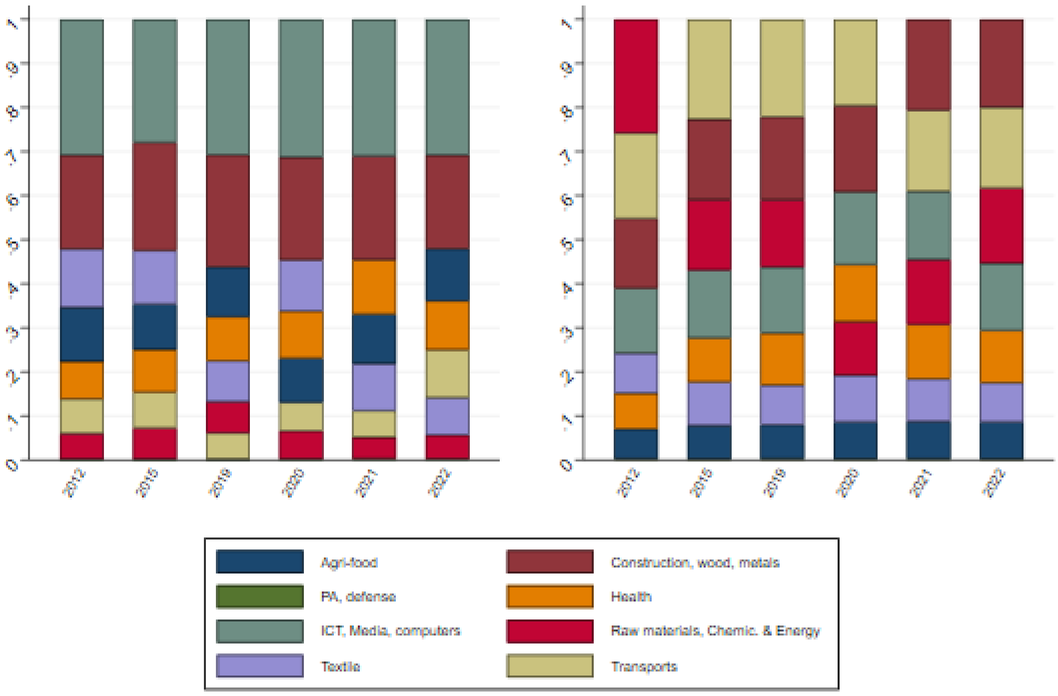

Table A.11- U.S. critical imports share by supply chain (left panel - % over total critical import value; right panel - % over total import value)

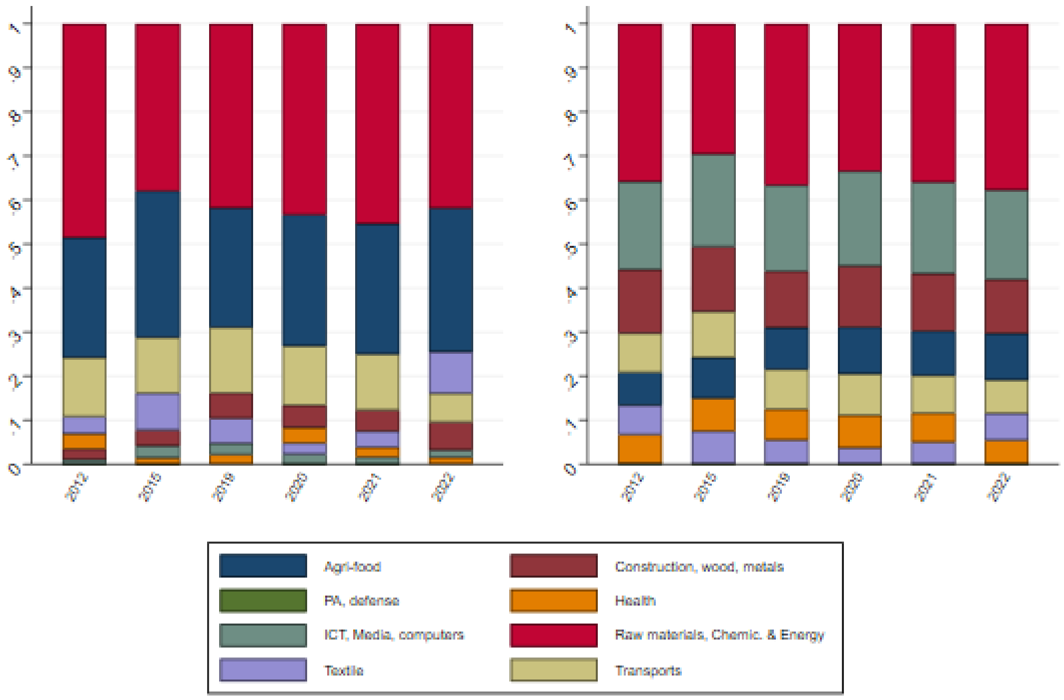

Table A.12- China critical imports share by supply chain (left panel - % over total critical import value; right panel - % over total import value)

B) European Union, Italy, France, and Germany critical import

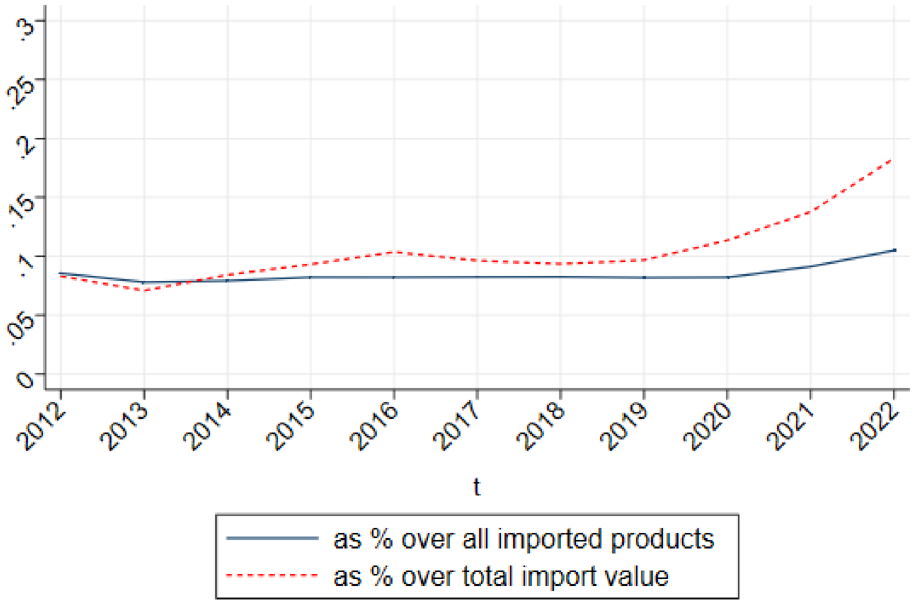

Table B.1- EU (including intra-area trade) critical imports (% over total imports)

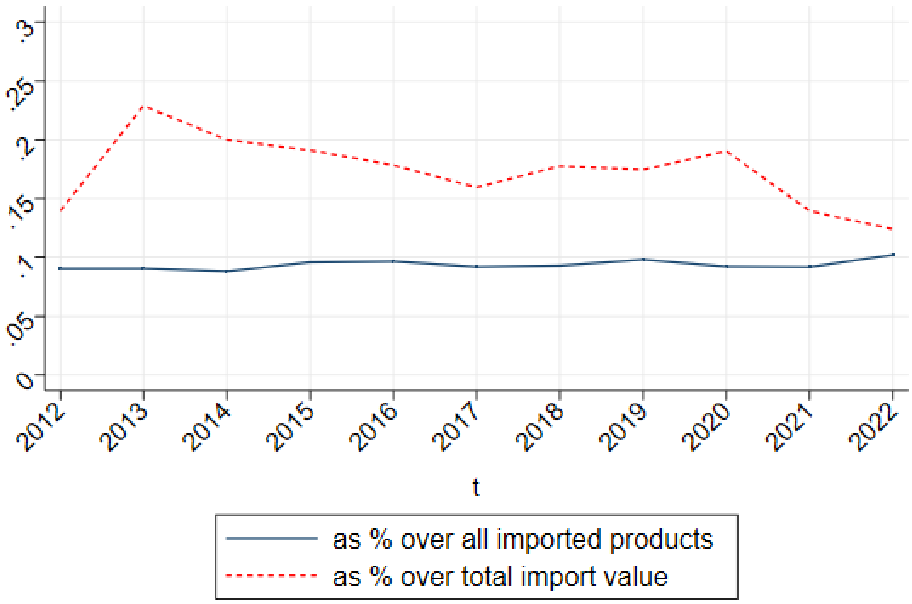

Table B.2- Italy critical imports (% over total imports)

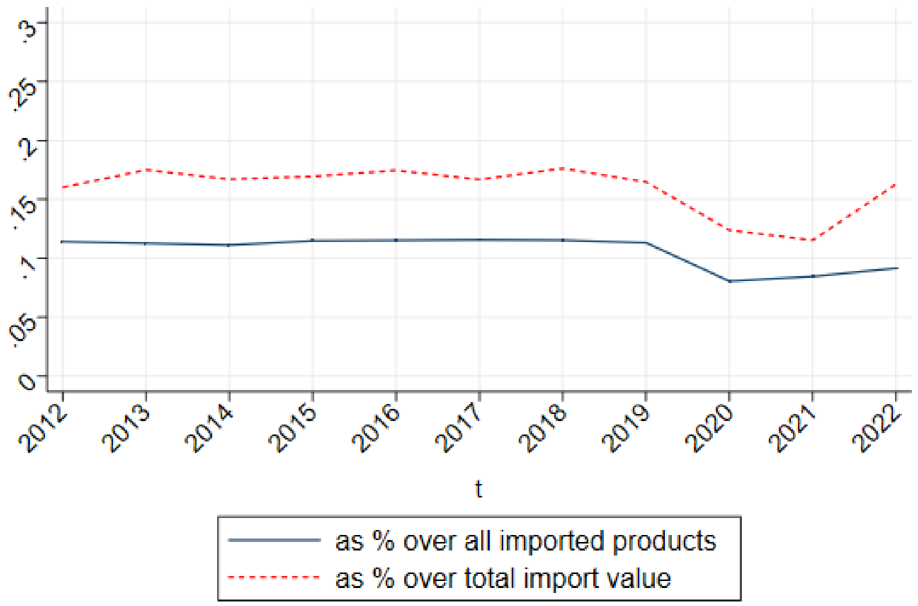

Table B.3- France critical imports (% over total imports)

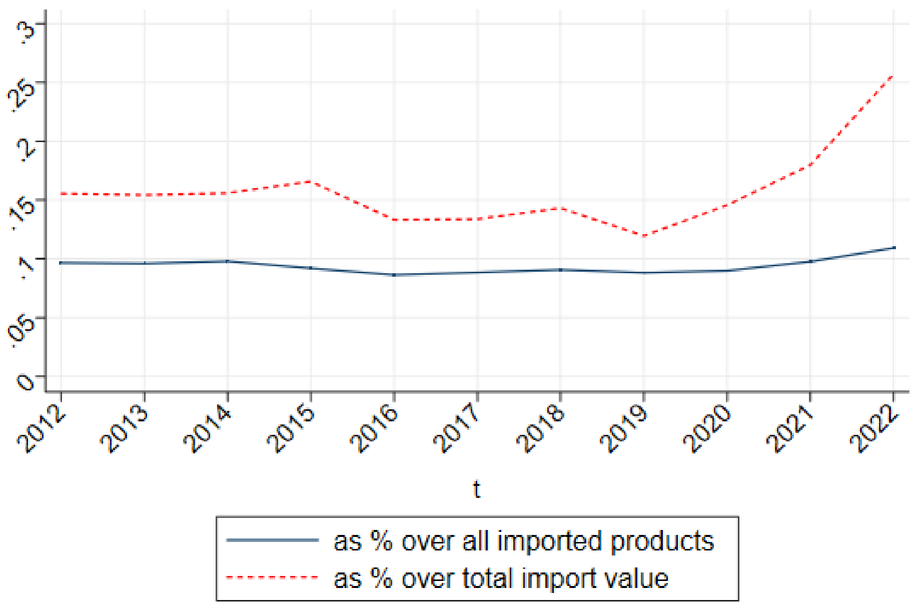

Table B.4- Germany critical imports (% over total imports)

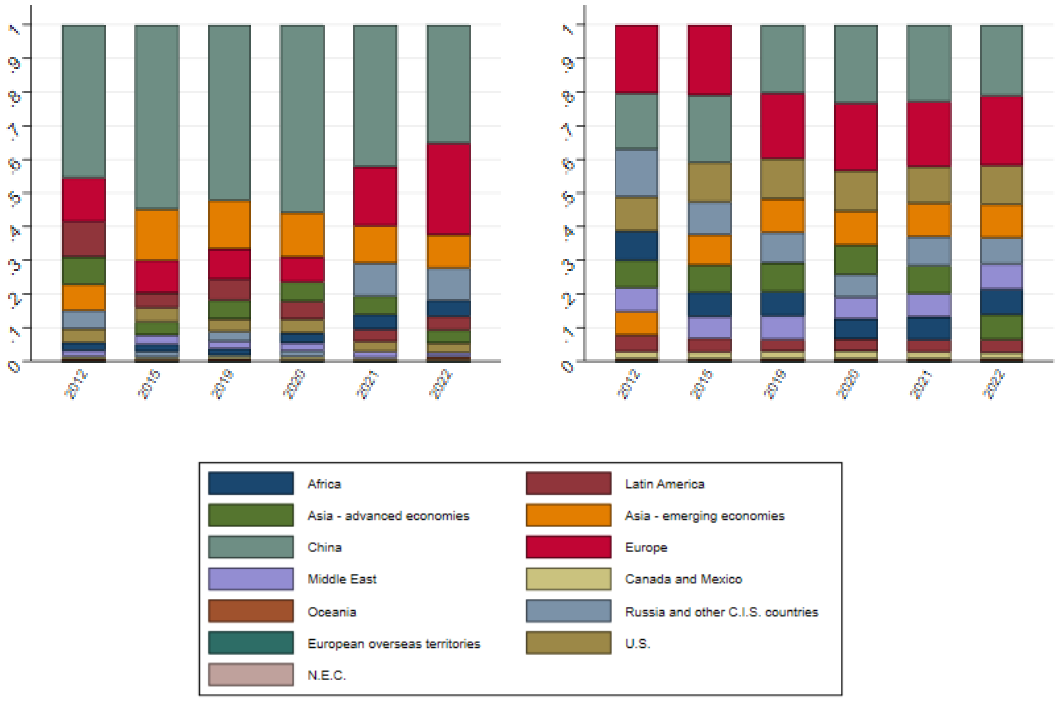

Table B.5- EU (including intra-area trade) critical imports share by supply area (left panel - % over total critical import value; right panel - % over total import value)

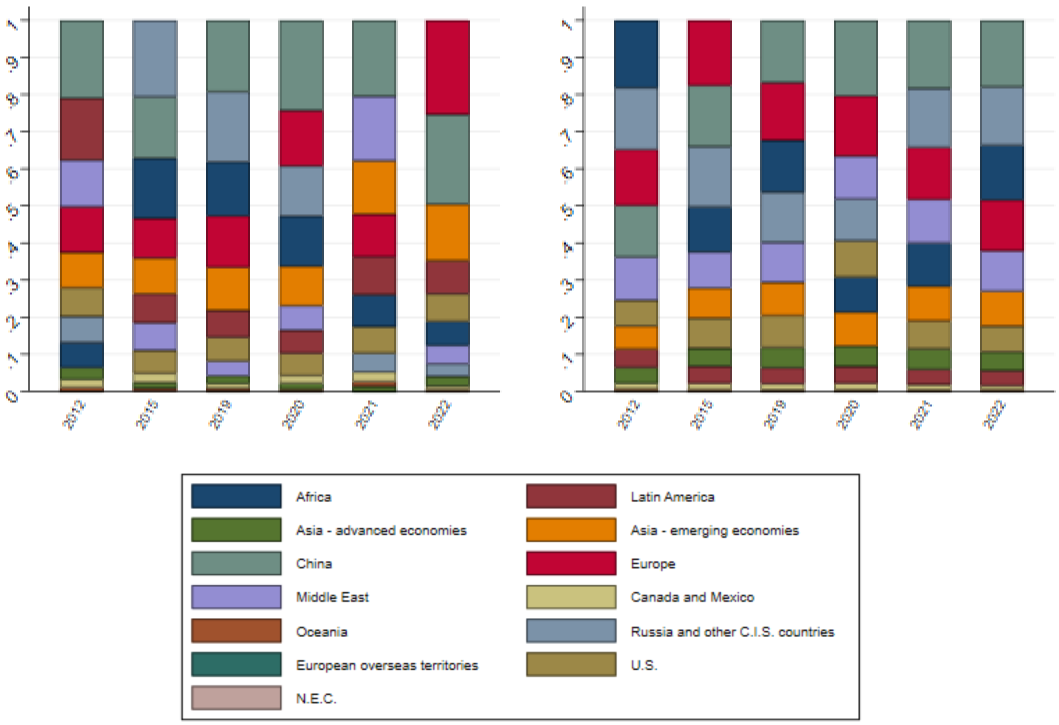

Table B.6- Italy critical imports share by supply area (left panel - % over total critical import value; right pane l- % over total import value)

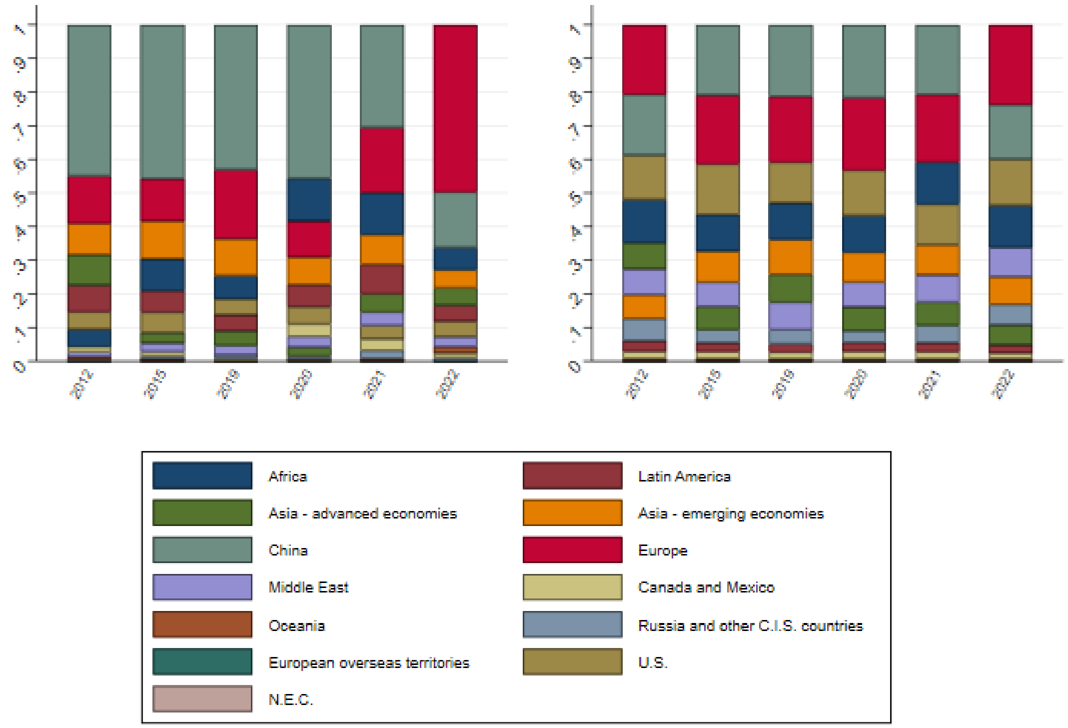

Table B.7- France critical imports share by supply area (left panel - % over total critical import value; right panel - % over total import value)

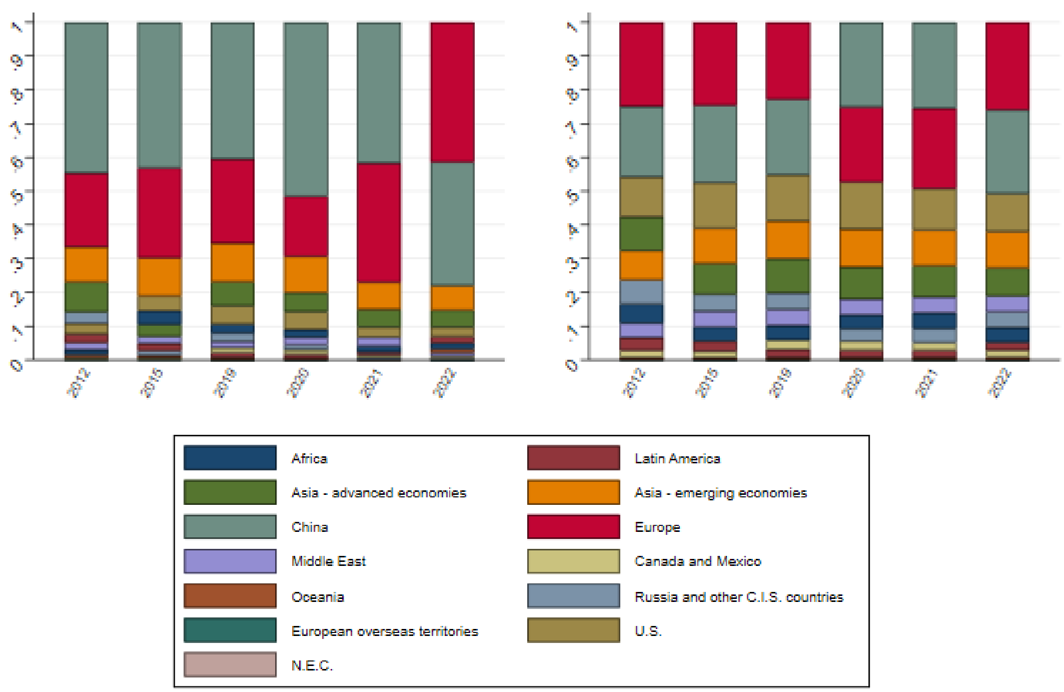

Table B.8- Germany critical imports share by supply area (left panel - % over total critical import value; right panel - % over total import value)

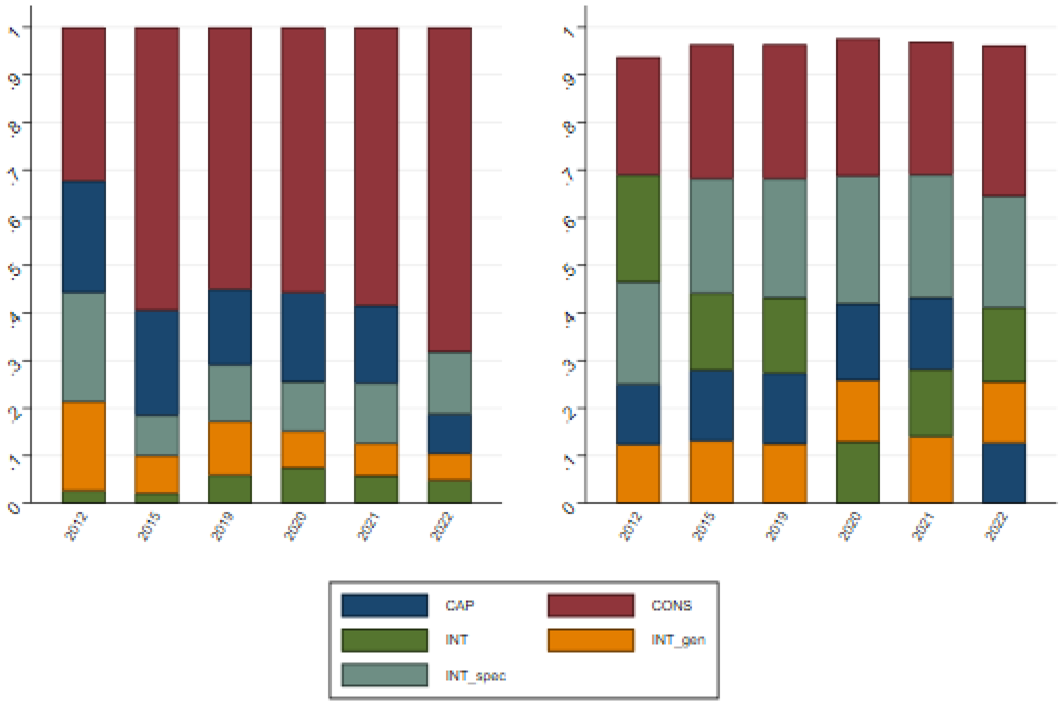

Table B.9- EU (including intra-area trade) critical imports share by end-use (left panel - % over total critical import value; right panel - % over total import value)

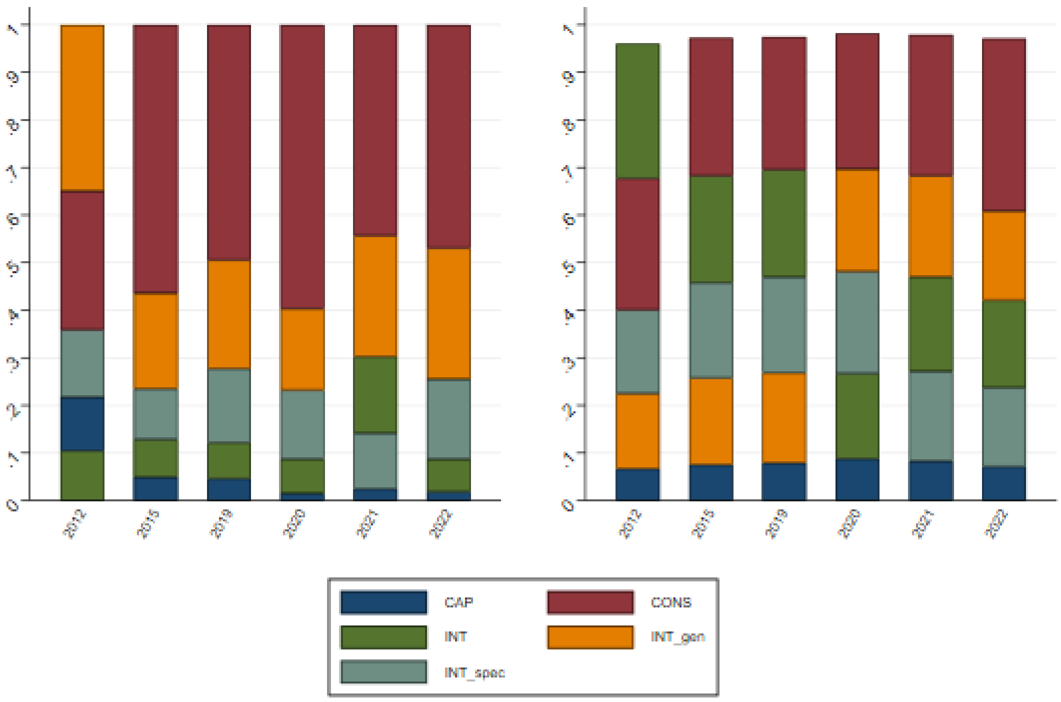

Table B.10- Italy critical imports share by end-use (left panel - % over total critical import value; right panel - % over total import value)

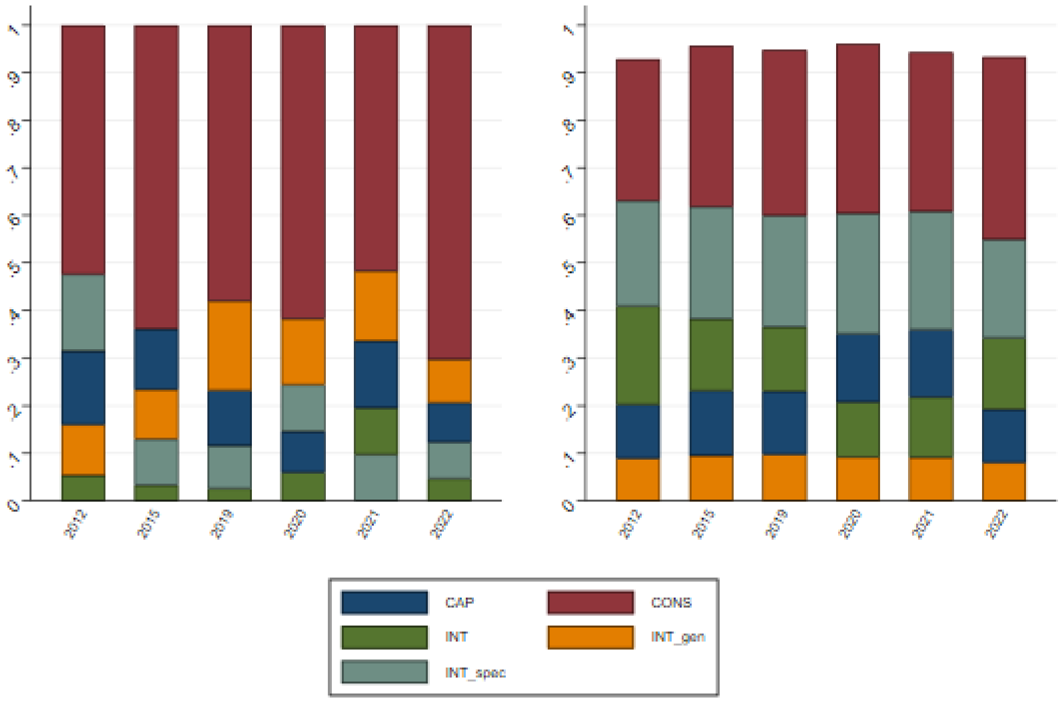

Table B.11- France critical imports share by end-use (left panel - % over total critical import value; right panel - % over total import value)

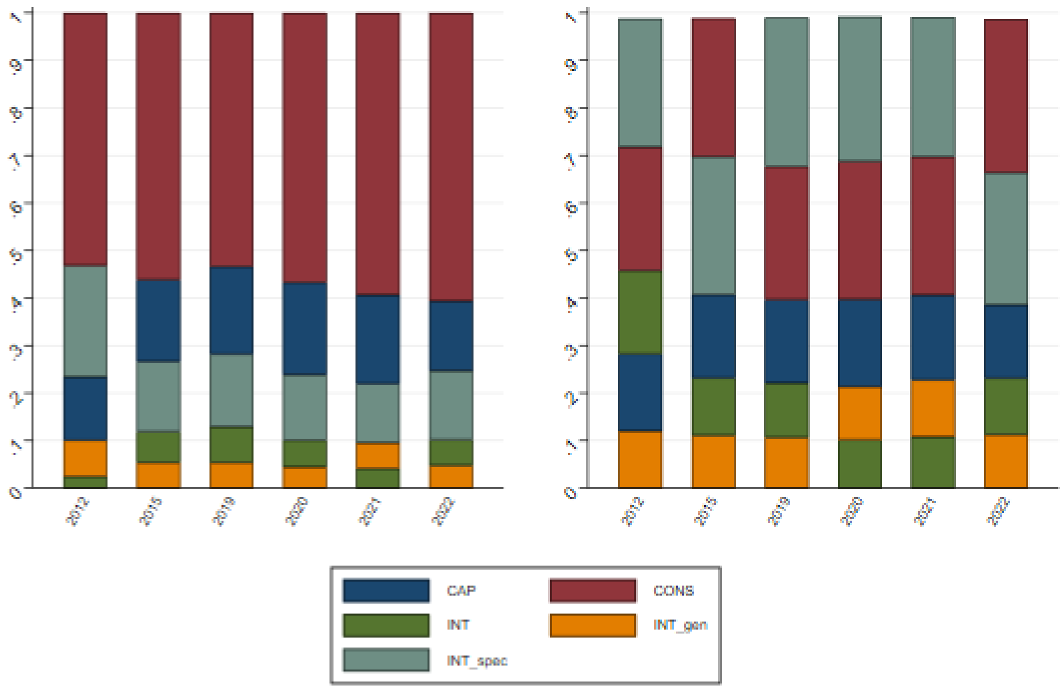

Table B.12- Germany critical imports share by end-use (left panel - % over total critical import vale; right panel - % over total import value)

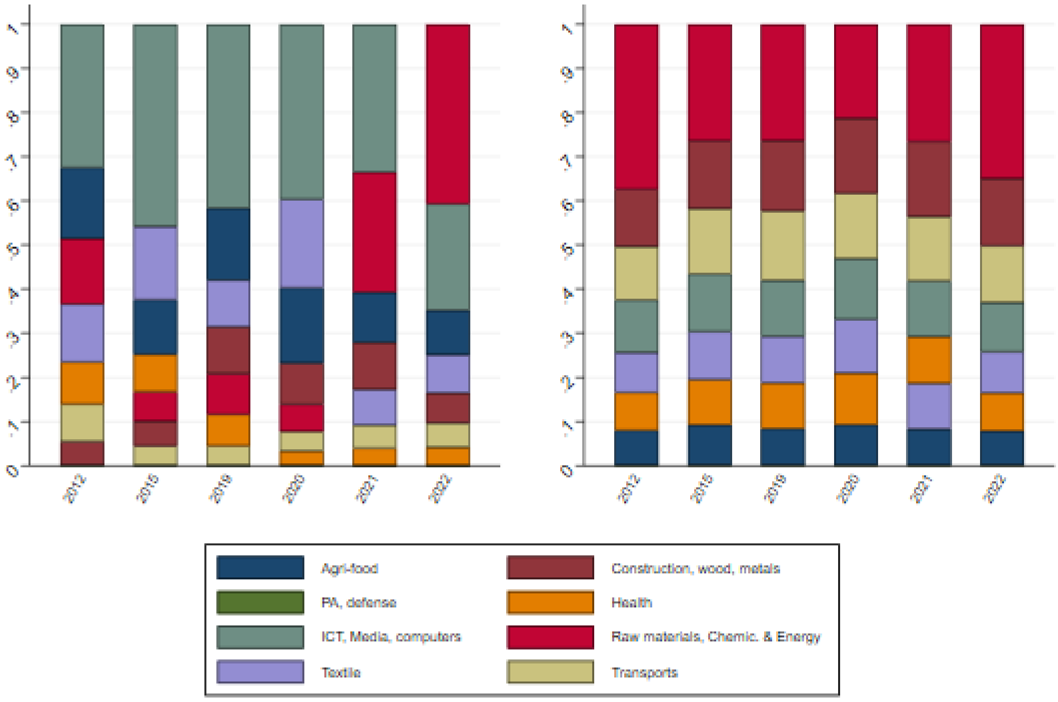

Table B.13- EU (including intra-area trade) critical imports share by supply chain (left panel - % over total critical import value; right panel - % over total import value)

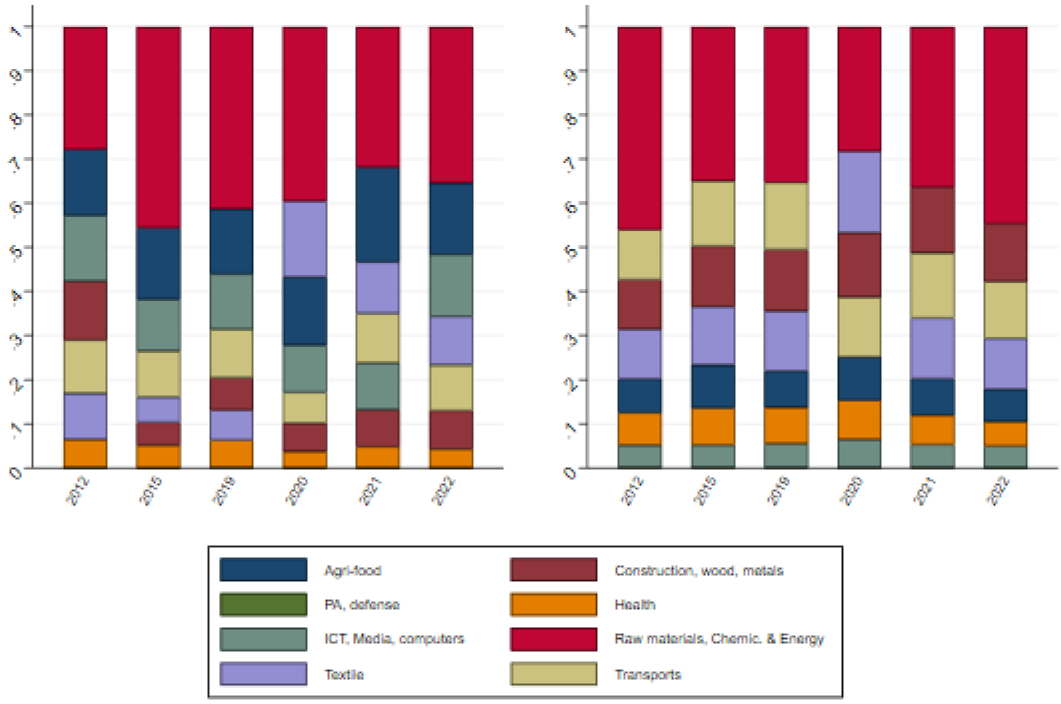

Table B.14- Italy critical imports share by supply chain (left panel - % over total critical import value; right panel - % over total import value)

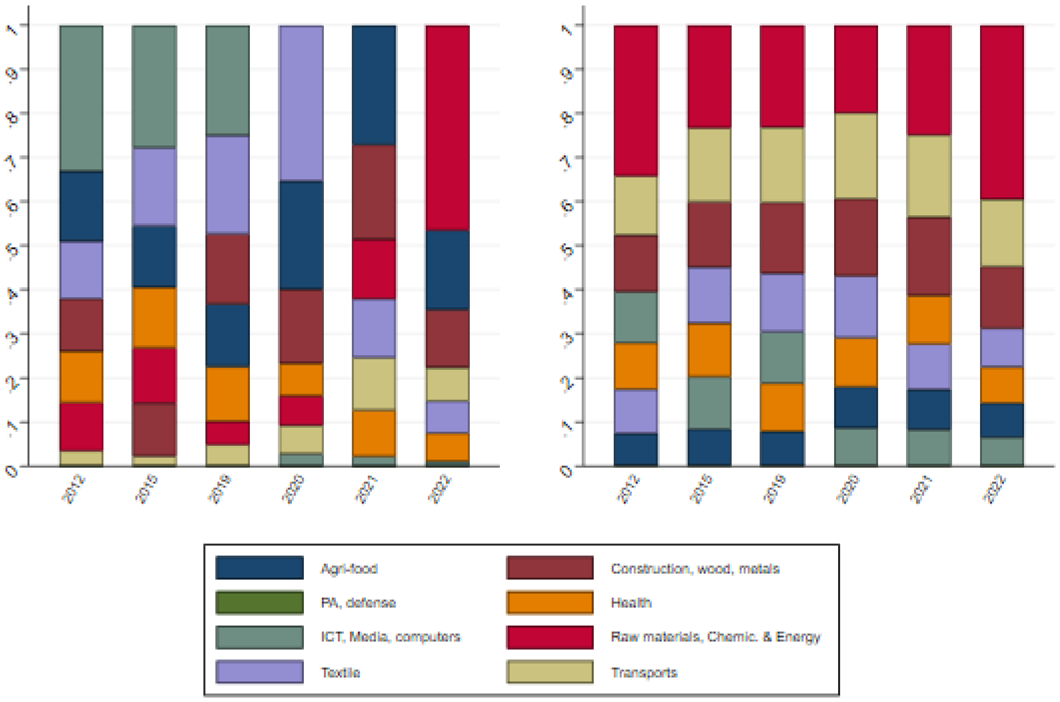

Table B.15- France critical imports share by supply chain (left panel - % over total critical import value; right panel - % over total import value)

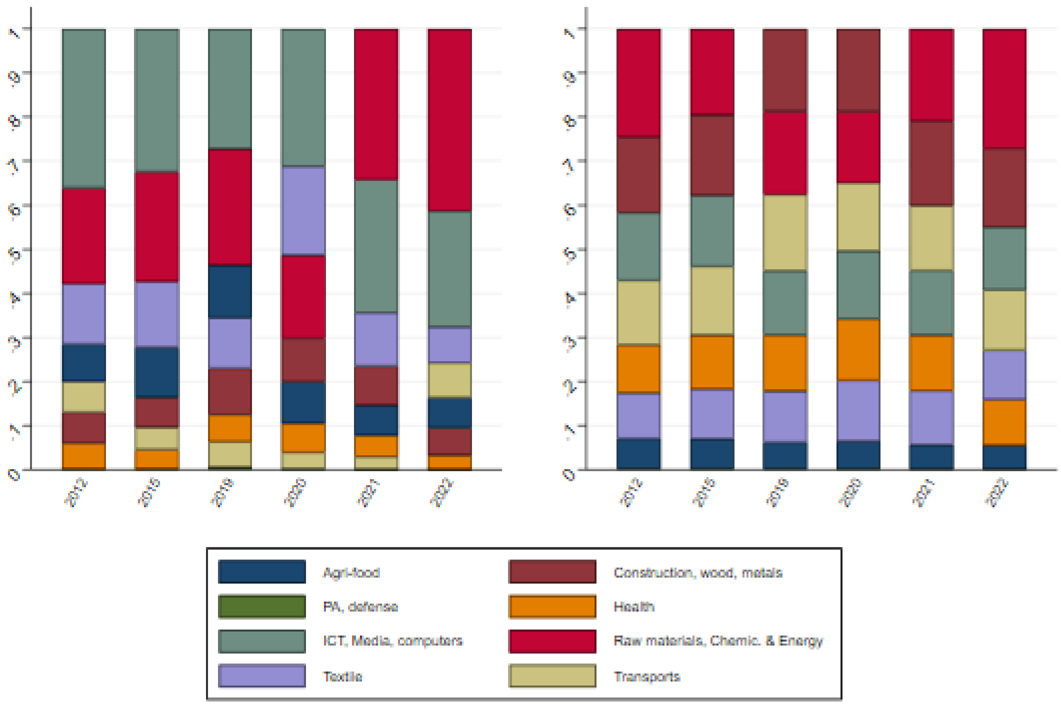

Table B.16- Germany critical imports share by supply chain (left panel - % over total critical import value; right panel - % over total import value)