Identifying European trade dependencies

Isabelle Mejean[*] Pierre Rousseaux[†]

March 28, 2024

Abstract

We review and extend upon existing literature using product-level trade data to identify trade dependencies that expose the European Union to potential disruptions. While acknowledging the significance of concentrated foreign input sourcing as a source of vulnerability, a comprehensive assessment of vulnerabilities should also consider the potential for substituting away from disrupted input sources, both domestically and abroad. This may necessitate devising novel statistical measures at the European level. We present a novel methodology that identifies trade dependencies by integrating these substitution sources. Our review encompasses normative arguments justifying public interventions to improve the resilience of value chains. We intersect our identified dependencies with a measure of geopolitical risk, their upstreamness in the value chain, and also focus on critical products and strategic green technologies. The specific targeting of these policies varies depending on the nature of risks they aim to mitigate. Finally, we discuss the range of policy tools available for crafting a resilience policy.

[*]Sciences Po and CEPR, Email address: isabelle.mejean@sciencespo.fr.

[†]CREST (Ecole Polytechnique, ENSAE), Email address : pierre.rousseaux@ensae.fr.

1 Introduction

The risks associated with global trade dependencies have been extensively discussed over the last three years. A primary catalyst for this heightened scrutiny stems from the disruptions brought about by the COVID-19 pandemic, which underscored the European Union's reliance on foreign nations for crucial commodities, notably medical supplies and pharmaceuticals. Between March 2020 and December 2021, the New York Fed's "Global Supply Chain Pressure Index" exhibited a consistent upward trend, reflecting the accumulation of disruptions along global value chains. Subsequently, the Russian invasion of Ukraine starkly demonstrated the potential weaponization of trade dependencies during periods of escalating international tensions.

The Global Value Chains (GVCs) represent intricate networks of interconnected processes, organizing the sequence of tasks involved in producing a good, spanning from its inception to the final purchase by end consumers. Over the past three decades, the geographical span of GVCs has significantly expanded, enabling firms and countries to maximize gains from trade (Antràs and Chor, 2021). In the meantime, the heightened concentration of activities within specific nodes of these value chains has potentially reduced the resilience of these production processes. First, shocks affecting a single node propagate along the chain, engendering "granular" risks and comovements (di Giovanni et al., 2020, Bonadio et al., 2021). Second, GVC structures are riddled with diverse externalities. These range from network externalities, which induce suboptimal investments in resilience (Grossman et al., 2021), to information frictions that limit firms' capacity to comprehend their overall exposure to foreign risks, beyond their immediate suppliers (Bui et al., 2022). Consequently, the hyper-globalization within GVCs exposes economies to a difficult trade-off between the benefits derived from specialization and the imperative to diversify risks.

Unexpected shocks to the global economy have certainly tilted the balance toward a reduced tolerance for trade-induced risks. Following the onset of the pandemic, policymakers in both Europe and the US voiced concerns regarding the lack of diversification in supply chains.[1] Calls for public interventions emerged to alleviate the concentration within GVCs, promote diversification, and establish more robust and sustainable supply chains. However, the design of these policies encounters complexities, primarily due to the earlier-mentioned trade-off. Given the underlying insurance motives, the optimal design of these policies necessitates should integrate factors such as the nature of risks the policies seek to mitigate, societal tolerance levels for risk, and the allocation of insurance costs between broader society and private actors involved in these value chains. Moreover, as global trade dynamics continue to evolve, any resilience policy should adopt a forward-looking approach, accounting not only for existing dependencies but also anticipating future dependencies in key value chains.

To make progress into this direction, this paper integrates academic perspectives on the resilience of global value chains with a data-driven examination of Europe's present and future dependencies. The aim is to formulate an appraisal of Europe's trade dependencies, which we argue serves as an indispensable first step for devising effective resilience strategies. Recognizing the trade-off between the economic efficiency inherent in specialized Global Value Chains (GVCs) and the strategic advantages derived from enhanced resilience against shocks, it becomes impera-

[1] This sentiment was encapsulated in various policy initiatives, such as the 2021 Executive Order on America's Supply Chains, emphasizing that "The United States needs resilient, diverse, and secure supply chains to ensure our economic prosperity and national security. Pandemics and other biological threats, cyber-attacks, climate shocks and extreme weather events, terrorist attacks, geopolitical and economic competition, and other conditions can reduce critical manufacturing capacity and the availability and integrity of critical goods, products, and services.". Similarly, France echoed these concerns in 2020: "The France of 2030 will have to be more independent, more competitive, more attractive. It is about no longer depending on others for essential goods, no longer risking critical supply disruptions." (Plan France Relance)

tive that public interventions aimed at fostering greater resilience in GVCs are well-targeted and thoughtfully designed.

Our diagnosis approach draws inspiration from existing tools proposed to aid in formulating resilience strategies. The European Commission proposed a "bottom-up" methodology to compile a list of products which resilience policies should prioritize. This method relies on detailed trade data to pinpoint vulnerabilities, defined as product categories predominantly sourced from a limited set of foreign countries. While trade data offer crucial insights into trade dependencies, we argue that refining the list of potential "vulnerabilities" is imperative. Firstly, our diagnostic process integrates existing production capacities within Europe. Secondly, it is essential to consider the potential for post-disruption diversification. While the current trade structure informs us about the degree of ex-ante diversification in foreign sourcing, disruptions in the supply chain can prompt diversification ex-post through supplier switching. Our diagnosis thus characterizes trade vulnerabilities according to the potential for ex-post diversification.

We also propose to complement the data-driven diagnosis with a more explicit analysis of the specific risks targeted by resilience policies. The term 'strategic autonomy' encapsulates various risks, spanning geopolitical risks amidst escalating international tensions, economic risks to industry competitiveness within GVCs, potential societal costs incurred in the case of disruptions to essential goods, and a lack of competitiveness regarding future dependencies, e.g. in green technologies. While each dimension may expose the society to sizeable economic costs, different risks do not call for identical public interventions. Thus, a clear delineation of the targeted objectives is crucial for efficiently designing public policies. Finally, we delve into the policy toolbox that governments could employ to craft resilience policies. It is imperative to establish mesurable objectives that permit systematic evaluation, ensuring the efficacy of public interventions. Subsequently, the resilience gains obtained through these measures should be evaluated in comparison to traditional trade benefits, such as efficiency and risk diversification.

Related literature: This paper contributes to various strands within the literature. Central to the field of international economics is the broad discussion on first- and second-moment gains from trade. While conventional (static) trade models primarily emphasize first-moment gains, the influence of trade on the *volatility* of economic activity is a central ingredient of open macroeconomic models. In the seminal Backus et al. (1992) model, trade is a source of risk sharing across countries, effectively smoothing economic fluctuations. While trade provides a natural hedge against country-specific shocks, specialization simultaneously increases countries' exposure to sector- or even firm-specific supply shocks (Caselli et al., 2020, di Giovanni and Levchenko, 2010, 2012). The impact of trade on overall volatility thus hinges on the balance between these contrasting forces. In a calibrated multi-country, multi-sector model, Caselli et al. (2020) contend that the risk-sharing property dominates. Conversely, di Giovanni and Levchenko (2012) account for the granular structure of production and trade, underscoring the heightened exposure to idiosyncratic supply shocks, which they argue outweigh the risk-sharing advantages of international trade.

Another branch of literature approaches this question from the perspective of international comovements. Early works like Frankel and Rose (1998) highlighted that countries with more extensive bilateral trade tend to exhibit more correlated business cycles. di Giovanni et al. (2018) offer empirical evidence supporting a causal link from trade to business cycle comovements. Kleinert et al. (2015) and Cravino and Levchenko (2017) emphasize the role of multinational connections as a conduit for the transmission of shocks across borders. A number of papers leverage quantitative multi-country, multi-sector models to quantify the impact of trade and global value chains on aggregate comovements (di Giovanni and Levchenko, 2010, Bonadio et al., 2021, di Giovanni et al., 2020).[2] Recent literature further incorporates evidence obtained from natural experiments. For example, Boehm et al. (2019) use the Tohoku earthquake to estimate the diffusion of supply disruptions from Japan to US affiliates of Japanese firms. Their findings underscore substantial complementarities in production functions, intensifying the spread of supply chain disruptions. Similarly, Lafrogne-Joussier et al. (2023) leverage the early exposure of French firms to the Covid pandemic, through Chinese input sourcing, to estimate the propagation of supply chain disruptions. They reveal that firms with higher inventories experienced a mitigated sales drop. Intriguingly, pre-disruption diversification of firms' supply chains does not shield them from shocks, when compared with non-diversified firms. This is due to non-diversified firms actively seeking new suppliers in the aftermath of the shock. Such evidence points to a possible substitutability between ex-ante and ex-post diversification strategies.

The literature examining the normative aspects surrounding these debates remains limited in comparison. Grossman et al. (2021) and Grossman et al. (2023) delve into equilibrium and first-best allocations within models wherein investments in resilience impart externalities on other firms within the production network. They derive policies that implement the first-best allocation, through a combination of subsidies to input purchases, network formation, and investments in resilience.[3] Aside from network externalities, other market failures surround discussions on strategic autonomy. Baldwin and Freeman (2021) formalize a potential divergence between private assessments of the risk-efficiency trade-off associated with trade and the social evaluation, which might place greater emphasis on risks. This divergence gains particular relevance in discussions concerning disruptions in "essential" products that furnish public goods and services. Escalating geopolitical tensions have prompted examination of the link between trade dependencies and the likelihood of conflicts. Thoenig (2023) introduces a quantitative toolkit to dig into this interaction. In this framework, trade influences the so-called "geoeconomic welfare gains," which can be positive or negative depending on the direction and extent to which conflict risk reacts endogenously to policy-induced shifts in trade flows.

Alongside academic contributions, a policy-oriented literature delves into the resilience motive for public policies (White House, 2021, US Council of Economic Advisors, n.d., OECD, 2021). Most relevant to what we do are publications that propose assessments of trade vulnerabilities (Bonneau and Nakaa, 2020, Jaravel and Mejean, 2021, European Commission, 2021, Baur and Flach, 2022, Vicard and Wibaux, 2023). As detailed in Section 2, a common feature of these papers is the use of fine-grained data to pinpoint segments within trade networks that concentrate vulnerabilities. While vulnerabilities within production networks can also emerge domestically, policy discussions predominantly revolve around the interntational segment of value chains, which has faced specific shocks in recent years. Consequently, vulnerabilities are delineated at product nodes heavily reliant on foreign sourcing (particularly from non-EU countries in the case of the EU) *and* where the sourcing heavily hinges on a single country. In comparison to existing literature, our approach refines empirical methodologies by incorporating additional data on domestic production capacities, and potential substitution opportunities. Moreover, we discuss the list of identified products in light of the diverse array of risks influencing trade relationships.

[2]For instance, Bonadio et al. (2021) examine the role of global supply chains during the Covid-19 pandemic using a multi-sector quantitative framework across 64 countries. Their findings suggest that around one quarter of the overall real GDP decline during the pandemic could be attributed to labor supply shocks transmitted through global supply chains. Importantly, they simulate a "reshoring" scenario, relocating foreign parts of value chains domestically, and demonstrate that domestic production does not inherently render countries more resilient to pandemic-induced contractions in labor supply.

[3]Elliott et al. (2022) also construct a model featuring endogenous production networks in which firms weigh the expense of diversifying input sourcing against the advantage of heightened robustness. They show that supply networks of intermediate productivity are fragile in equilibrium, even though this is always inefficient.

The rest of the paper is organized as follows. In section 2, we explain our strategy for identifying a list of potential vulnerabilities to EU trade and present the data and results. In Section 3, we study the list of vulnerabilities in light of the various risks associated with international trade dependencies. Based on the analysis, we discuss in Section 4 the set of policies available to reduce the EU's exposure to such vulnerabilities and discuss the design and governance of these policies.

2 A diagnosis of trade vulnerabilities

Given the efficiency-resilience trade-off, resilience policies must target specific products, crucial to the overall fragility of economic systems to foreign shocks. To achieve this, a comprehensive approach begins with a diagnosis of trade vulnerabilities. We build upon the methodology developed by the European Commission (European Commission, 2021), which we extend to take into account domestic production capacities as well as substitution opportunities within products, across source countries.

2.1 The bottom-up approach of the European Commission

Table 1, borrowed from Vicard and Wibaux (2023), outlines the methodology in European Commission (2021), encompassing three criteria for evaluating the EU's trade dependencies. The EC methodology is also compared with alternative strategies used in Bonneau and Nakaa (2020), Jaravel and Mejean (2021) and Baur and Flach (2022). The EC criteria measure distinct facets of EU's trade dependencies using product-level trade data: 1) the concentration of extra-EU imports, 2) the significance of extra-EU imports in EU imports, and 3) the ability to substitute with EU production. The concentration of European extra-EU imports is assessed via the product-level Herfindahl-Hirschman Index (HHI). A product surpasses the concentration threshold (HHI $>$ .4) if imports are heavily skewed from particular sources, exposing EU importers to country-specific supply shocks. The second criterion is based on the proportion of extra-EU imports out of total European imports. The third criterion is the ratio of extra-European imports to total European exports. A product is considered vulnerable if more than half of the import demand from EU member states is sourced from outside of the EU, while the value of these imports is larger than the total value of EU exports in that product category. The second and third criteria are thus meant to proxy for the existence of production capacities within the European Union, as measured by intra-EU trade flows (criterion 2) as well as exports from the EU to the rest of the world (criterion 3). These criteria intend to identify vulnerabilities arising from heavy reliance on non-EU imports, highlighting the significance of EU production capacities as an insurance against shocks affecting imported inputs.

Table 1: Vicard and Wibaux (2023)'s review of methodologies used to identify vulnerable products

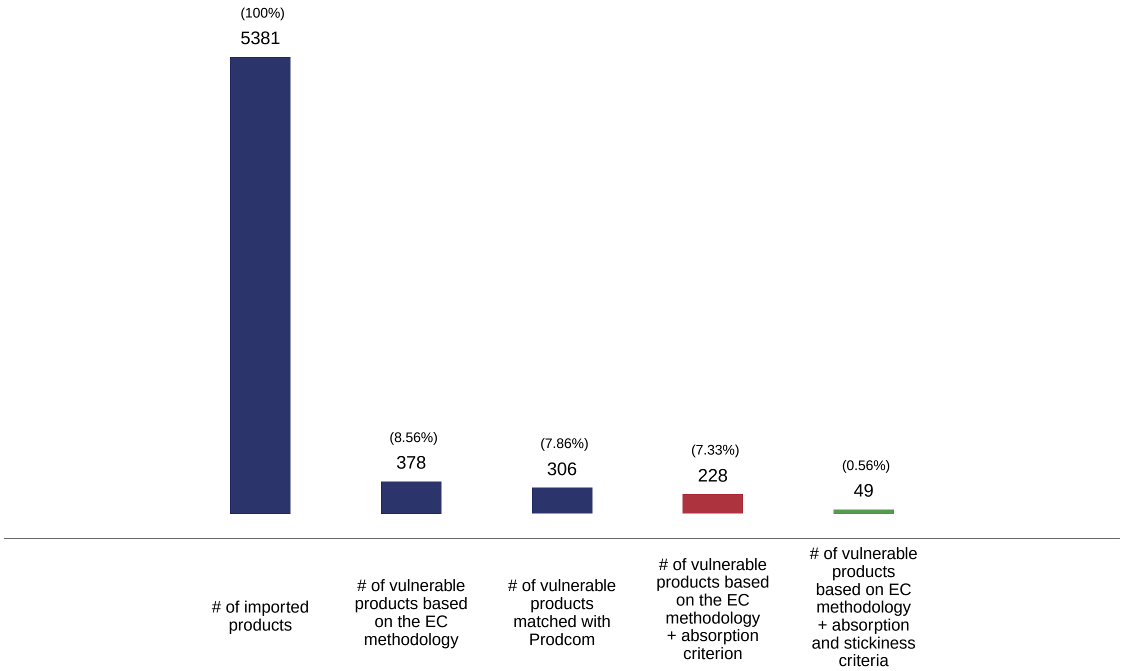
	European Commission (2021)	Bonneau and Nakaa (2020)	Jaravel and Mejean (2021)	Baur and Flach (2022)
Criteria 1	**Concentration of imports:** HHI $>$ 0.4	**Source of imports:** Extra-EU imports $>$ 50%	**Source of imports:** a majority of extra-EU imports	**Relevance of the goods for domestic production:** 3 most used intermediate goods in the 5 most important sectors of the economy
Criteria 2	**Importance in demand:** ratio extra-EU imports / total EU imports $>$ 0.5	**Concentration of imports:** HHI $>$ 0.5	**Concentration of imports:** HHI $>$ 0.5	Concentration of imports: HHI $>$ 0.33
Criteria 3	**Substitutability by EU production:** ratio extra-EU imports / total EU exports $>$ 1	**Diversification potential:** centrality risk $>$ 2.5 (Y. Korniyeko, M. Pinat and B. Dew, 2017)	**Granularity of demand:** one French firm represents at least 90% of imports	**Substitutability by domestic production:** ratio imports/exports $>$ 1

Various studies, including the French Treasury, the French Council of Economic Advisors, and the German CESifo, have employed methodologies similar to the previously discussed approach. Import concentration remains a key aspect across these analyses. Bonneau and Nakaa (2020) and Jaravel and Mejean (2021) supplement these criteria by assessing the significance of extra-EU imports. Bonneau and Nakaa (2020) add a measure of risk centrality as a proxy for the absence of substitution opportunities. Jaravel and Mejean (2021) instead rely on firm-level import data to measure the granularity of extra-EU imports.[4] Finally, Baur and Flach (2022) add a measure of the product's importance for domestic production, emphasizing vulnerabilities affecting domestic industries through value chains. We will come back on this dimension of vulnerabilities in Section 3.2.

We implement the bottom-up strategy outlined by the European Commission using the CEPII-BACI database, which comprehensively covers worldwide bilateral trade flows at a detailed 6-digit product level. As detailed in Vicard and Wibaux (2023), the trade vulnerabilities identified by the EC methodology vary heavily from one year to the next. We smooth out this volatility by pooling trade data over five consecutive years, from 2015 to 2019, thus focusing on persistent trade vulnerabilities. Our approach consolidates bilateral imports across the 27 members of the European Union, disregarding intra-EU trade flows. Subsequently, we apply the three criteria proposed by the European Commission. In total, we start with a list of 5,381 different products, 378 of which being considered "strategic dependencies" based on the EC's approach (see the first two bars of Figure 1). These identified strategic dependencies collectively account for 8.56% of the total value of aggregate imports. Further insights into the nature of these products will be presented in Section 3. Before delving into that discussion, we propose refining the analysis by incorporating two additional criteria that capture substitution opportunities following shocks to foreign inputs.

[4]Their argument is that more concentration in imports across firms is likely to induce more exposure to idiosyncratic shocks as firms tend to concentrate sourcing on a limited number of suppliers.

Figure 1: Number of "strategic dependencies" and their contribution to aggregate imports, based on various criteria



Notes: The figure shows the number of strategic dependencies (and their contribution to the value of EU imports) using various methodologies, starting with the strategy proposed by European Commission (2021) (second blue bar) and adding criteria based on the ratio of imports over domestic absorption (red bar) and the degree of product stickiness (green bar). See details in the main text. Source: CEPII-BACI and Prodcom for 2015 to 2019.

2.2 Controlling for intra-EU production capacities

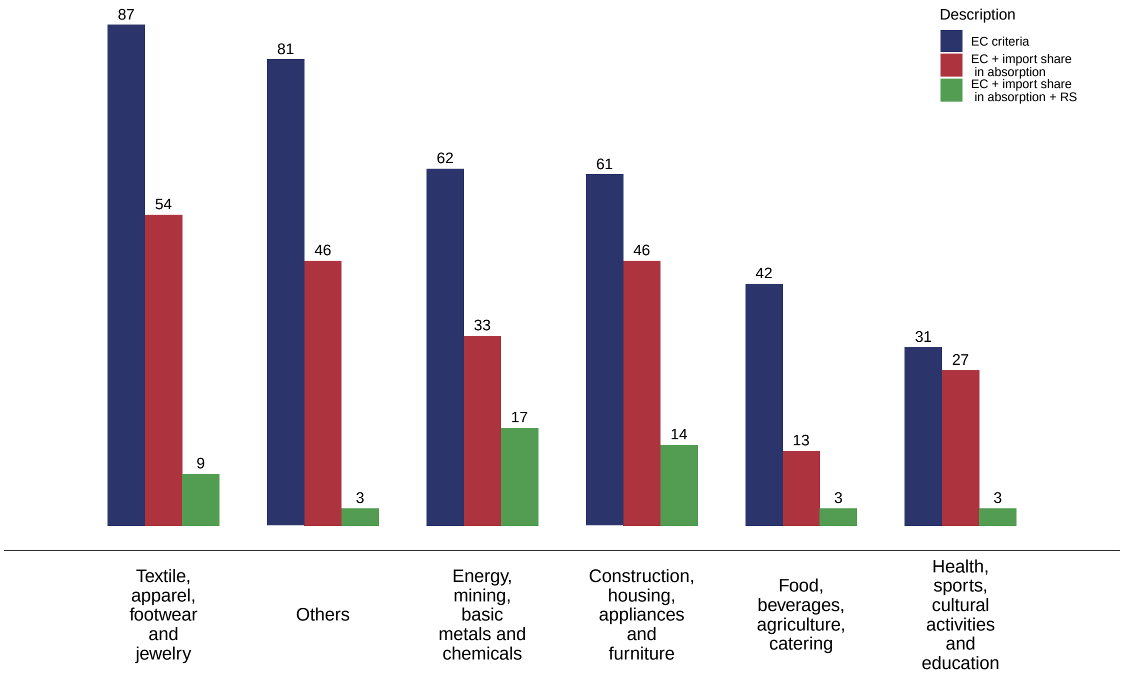
The EC approach primarily relies on the structure of trade, offering insights into ex-ante exposure to foreign shocks. However, recent experience, including in the context of the Russian gas crisis, have underscored the significance of substitution opportunities post-shock as a crucial aspect of resilience (Moll et al., 2023). Dependencies on trade become more detrimental when reliance lacks a balance with domestic production capacities, which could act as a fallback in the event of disruptions in foreign sourcing. The EC's third criterion implicitly aims to capture this potential substitution between imports and domestic production. However, the trade data used by the EC acts as an imperfect proxy for domestic production capacities. For instance, exporting the same product back and forth can lead to significant trade volumes that do not reflect the actual level of production. It is therefore crucial to integrate production data into the analysis of import substitution. Unfortunately, measuring domestic production capacities presents complexities due to the lack of statistics on output at a sufficiently detailed level of disaggregation. Commonly used datasets for measuring domestic output include the OECD-STAN database, covering 27 countries and a maximum of 153 ISIC sectors, the GGDC's World Input Output Database (43 countries and 56 sectors) or the UNIDO-INSTAT dataset (117 countries and 161 manufacturing sectors). However, the European Union possesses relatively robust resources. The Council of the European Union sanctioned the creation of a European survey on manufacturing production in 1991, resulting in the Prodcom dataset. This dataset provides annual statistics on output for 4,000 manufacturing products, using a nomenclature compatible with the Combined nomenclature, the European 8-digit version of the HS nomenclature used in trade statistics. In essence, the Prodcom dataset thus enables a systematic comparison between trade and production data for EU member states, at a granular level of disaggregation.

We leverage the availability of these datasets to enhance the EC's strategy by introducing a fourth "absorption" criterion. According to this criterion, a product is deemed vulnerable if over 50% of domestic absorption (output plus imports less exports) originates from foreign sources.[5] Unfortunately, the quality of the data is not perfect and we lose a number of products in the process. Out of the initial 378 products identified as strategic dependencies using the EC's methodology, 306 products can be merged with production data. After applying the absorption criterion, we identified 228 products as vulnerable (Figure 1, third and fourth bars). Controlling for domestic production capacities thus reduces the list of identified vulnerabilities, now accounting for approximately 7.3% of European imports. Remarkably, this reduction persists despite criteria 2 and 3 of the EC approach intending to capture the existence of domestic production capacities. This underscores the crucial role of incorporating domestic production measures within the overall diagnosis framework.

The domestic absorption criterion not only fine-tunes the list of strategic dependencies but also alters the sectoral distribution of these dependencies (see Figure 2). Notably, 70% of strategic dependencies are concentrated within the textile, construction, energy and mining, and health sectors. A striking observation is that the absorption criterion significantly reduces the number of vulnerable products in the agricultural sector, from 42 to 13 products. This decline isn't unexpected, considering the European Union's historical support for agricultural production through its Common Agricultural Policy. Within this sector, the advantages of risk-sharing through trade with suppliers outside of the EU are likely substantial. In times of fluctuating domestic agricultural production, imports from non-EU sources can serve to supplement and stabilize supply. From that point of view, products exhibiting diversified domestic absorption, involving a mix of domestic and foreign products, even if primarily sourced from one country, may not be considered vulnerable.

[5] Here as well, both production and trade data are initially aggregated across EU member states and over time. We obtained European output statistics for over 3,700 Prodcom products, which can be linked to 4,800 HS6 categories. However, it is important to exercise caution when interpreting these statistics due to a substantial amount of missing data in the Prodcom dataset. Further details on this are available in Appendix A.1.

Figure 2: Comparison of the sectoral distribution of three lists of strategic dependencies



Notes: The figure illustrates the sectoral distribution of identified strategic dependencies, using the EC methodology (blue bars), the strategy augmented with an absorption criterion (red bars) and the list that further incorporates the stickiness indicator (green bars). The broad sectors are taken from the UN-BEC classification. Source: CEPII-BACI and Prodcom for 2015 to 2019.

2.3 Controlling for ex-post substitution opportunities

The selection of potentially vulnerable products, based on observed trade and production patterns, inherently assumes that foreign shocks cannot be diversified ex-post, through substitution away from countries and firms facing supply constraints. This conservative assumption serves as a natural starting point, given existing evidence of strong complementarities between inputs in production functions. Boehm et al. (2019) thus find that firms affected by the Tohoku earthquake adjusted their output almost proportionally to the reduction in their imports from Japan, suggesting a production function closely resembling Leontief.[6] However, finding by Lafrogne-Joussier et al. (2023) suggest that ex-post substitution patterns may exist in some cases. Among French firms exposed through their supply chain to the early lockdown in China in January 2020, they find no discernible difference between firms that were diversified ex-ante and firms that were not.[7] The reason, they show, is that firms that were not diversified ex-ante are systematically more likely to find new foreign partners immediately after the shock.

We propose integrating the potential for ex-post substitution into our diagnostic framework by introducing a metric called *stickiness* that we borrow from Martin et al. (2020). Their study employs firm-to-firm panel data to establish a product-level measure of stickiness, derived from the average duration of relationships between firms. Longer durations, given a consistent match quality, suggest various frictions that hinder firms from switching between input suppliers.[8] In presence of sizeable frictions, firms are more likely to be stuck into their existing relationships at

[6] For a detailed discussion on substitution patterns, particularly in the context of the European energy crisis, refer to Moll et al. (2023).

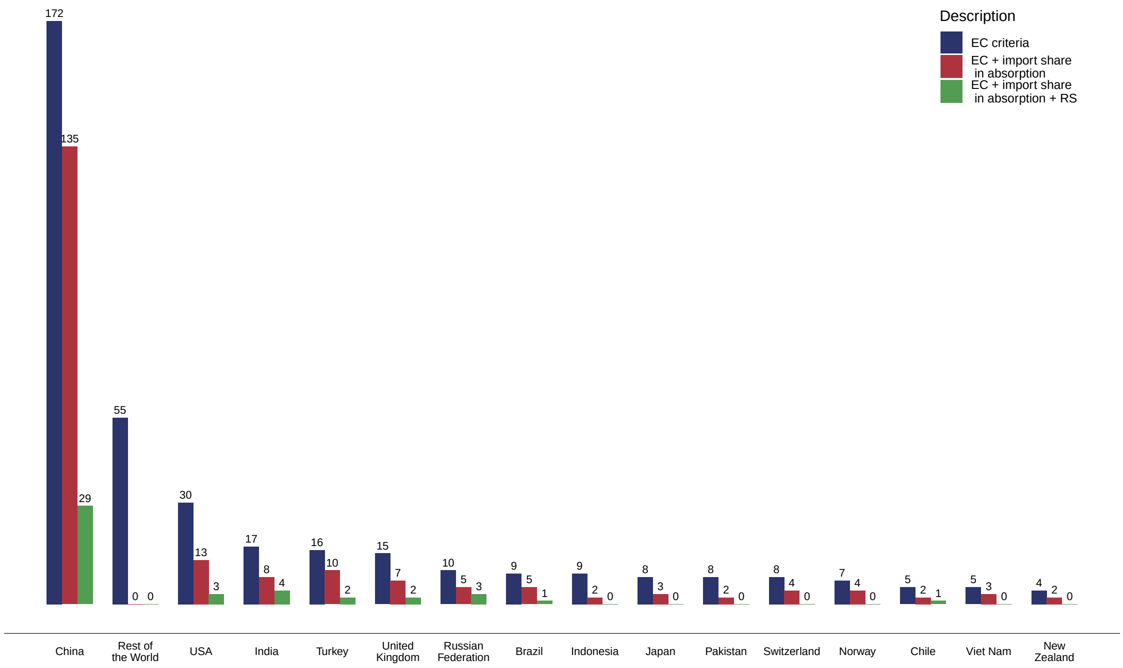
[7] Ex-ante diversification here refers to firms importing the same 8-digit product from both China and another foreign country, six months before encountering disruptions in the supply chain related to Chinese inputs.

[8] These frictions encompass search frictions constraining importers' knowledge of alternative suppliers, as well as costs — both fixed and variable — associated with a switch from one supplier to another. The empirical approach by Martin et al. (2020) effectively captures both sources of frictions.

the time the shock hits, thereby increasing associated costs. Strategic vulnerabilities concentrated in sticky products become more concerning from this perspective.

The final bar in Figure 1 narrows down the selection of products to "sticky" products, as defined by a degree of product stickiness within the last quartile of the entire distribution.[9] We set this threshold to focus on the stickiest products in the entire distribution, i.e. those with a stickiness relationship exceeding 3.2 (out of 4). Arguably, the choice of this threshold is somewhat arbitrary and varying the threshold up (resp. down) would mechanically increase (resp. reduce) the strength of the selection associated with the stickiness criterion. This refined criterion results in a set of 49 products, accounting for 0.5% of European imports. As shown in Figure 2, these products are notably concentrated within the energy, mining, basic metals and chemicals sector. Additionally, the majority of these strategic dependencies are associated with products primarily sourced from China, as highlighted in Figure 3. Table C1 in the Appendix provides a list of these strategic dependencies, detailing the main sourcing country and the HHI concentration index.[10]

Figure 3: Comparison of the geographical distribution of three lists of strategic dependencies



Notes: The figure illustrates the geographical distribution of identified strategic dependencies, using the EC methodology (blue bars), the strategy augmented with an absorption criterion (red bars) and the list that further incorporates the stickiness indicator (green bars). "Rest of the World" aggregates all remaining countries associated with no more than three vulnerable products. Source: CEPII-BACI and Prodcom for 2015 to 2019.

2.4 Improving the diagnosis with better data

While trade data are readily accessible, understanding production capacities within the EU is constrained by limitations in available statistics. The Prodcom dataset, employed to establish our fourth criterion, suffers from a considerable number of missing values, as explained in Appendix A.1. It remains uncertain whether these missing values indicate the absence of product-level production capacities in the respective country or are due to data quality issues such as insufficient coverage, misreporting, or other discrepancies. Given the existing statistical infrastructure at the

[9]Figure B1 in Appendix reproduces the cumulative distribution function of the stickiness measure, in the entire distribution and within the list of strategic dependencies identified in Sections 2.1 and 2.2.

[10]In Appendix Table C2, we list an additional 56 products that enter the list of trade vulnerabilities when we set a less stringent criterion for stickiness, at the 50th percentile of the distribution in Martin et al. (2020).

European level, enhancing the quality of these data might not incur significant costs. On the other hand, the benefit of acquiring more accurate information on product-level production capacities would be substantial.

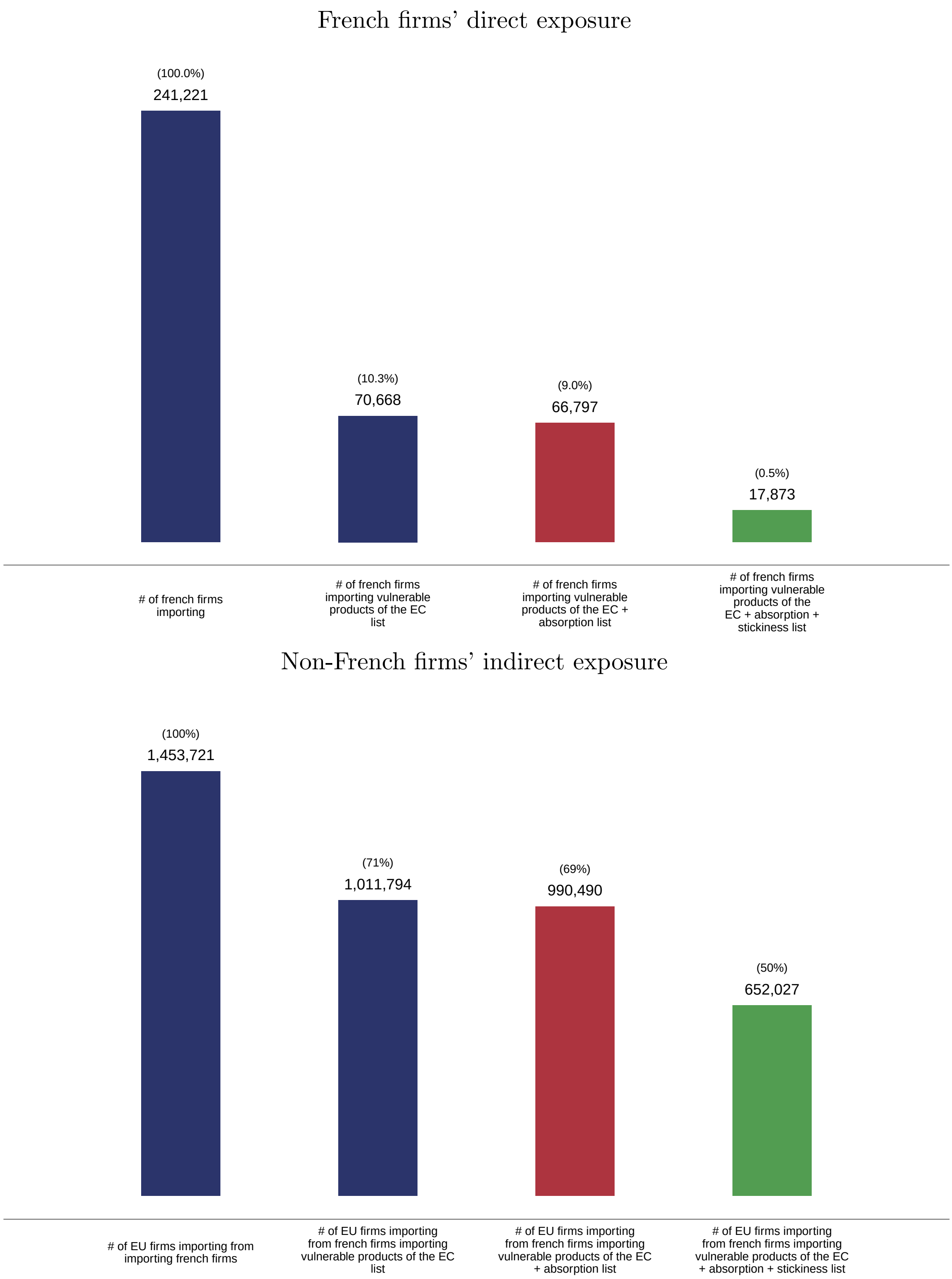
Another dimension that is missing from existing diagnoses of trade vulnerabilities is indirect exposure to strategic dependencies. Indirect exposure arises when a firm, although not directly importing from non-European countries, faces exposure to foreign shocks because its suppliers are themselves directly exposed. Evaluating these indirect exposures poses challenges due to the necessity for data on firm-to-firm linkages coupled with firm-level trade exposures.[11] Here as well, the European Union could make significant progress in this realm by leveraging existing data resources. Intra-EU trade data are already collected comprehensively at the firm-to-firm level, and used to calculate VAT compensations across Member States. These datasets capture all transactions involving a producer in one Member State and its partner in another, providing detailed insights into indirect trade exposures when matched with firm-level import data – also comprehensive for imports from outside the EU.[12] The EU Regulation number 2019/2152 on European business statistics marks an essential initial step in this direction. It acknowledges the necessity of harmonizing and exchanging micro-data within the European Union to modernize statistical information on firms' activity. Unfortunately, the exchange of micro-data, critical for consolidating these sources, remains confined to statistical purposes and doesn't anticipate use for research purposes. Unlocking the potential of these datasets for research could significantly enhance our understanding of indirect trade exposures within value chains.

We summarize the potential insights that such data would deliver using the French context as an example. In Figure 4, the top panel illustrates the number of French firms (and their contribution to French imports) that are directly exposed to "strategic dependencies", as defined earlier. By merging these data with French intra-EU export data at the firm-to-firm level, we can pinpoint all non-French European firms indirectly exposed to these dependencies through their interactions with French counterparts (Figure 4, bottom panel). Between 2015 and 2019, 70,668 French firms (resp. 17,873 firms) have been exposed to strategic dependencies as defined using the EC bottom-up approach (resp. the augmented EC bottom-up approach). These firms respectively represent 29 and 7% of the whole population of French firms. Their imports of these products constitute 10.3 and 0.5% of the value of France's non-European imports. Merged with intra-EU exports, these data reveal important spillovers to non-French European firms. More specifically, there are 1,011,794 European firms (resp. 652,027 firms) that are indirectly exposed to strategic dependencies through their interactions with the above-mentioned French firms. The combined value of their imports from France is equal to 991 billions euros, 70% of France's intra-EU exports (resp. 695 billions, 50% of intra-EU exports). Whereas these firms may not be directly exposed to European strategic dependencies, they are indirectly. Such indirect exposure is concerning because shocks propagate along value chains, beyond the node of direct exposure. Additionally, firms with indirect exposure often have limited awareness of their risk exposure. Consolidating trade data across Member States could offer policymakers and companies vital insights into the extent and origins of trade dependencies.

[11] Dhyne et al. (2020) address this challenge by combining firm-to-firm sales data for Belgium with firm-level foreign trade data. Their study reveals that while most Belgian firms extensively use foreign inputs, only a small subset directly imports them. The discrepancy between the granularity in direct trade and the widespread exposure of firms to foreign inputs suggests potential information frictions regarding firms' knowledge about their own exposure.

[12] In some Member States like Belgium or Portugal, such data can further be matched with domestic firm-to-firm transactions, collected for VAT purposes.

Figure 4: Indirect exposure to strategic dependencies, through firm-to-firm trade



Notes: The top panel presents statistics on the number of firms and their contribution to French imports from non-EU countries, that are exposed to EU trade dependencies, through their imports. The bottom panel shows statistics on firms that are indirectly exposed, through their interactions with French exposed importers. The top panel uses customs data on firm-level extra-EU imports. The bottom panel uses customs data on firm-to-firm intra-EU exports. A firm is considered directly exposed if it imports at least one product which is classified as a strategic dependency. A firm is considered indirectly exposed if it imports from a French firm that is directly exposed. Figure B2 details the geographical distribution of the number of indirect exposures. Figures B3 and B4 in Appendix B.1 reproduce the analysis excluding French wholesalers. Source: French Customs data for 2015 to 2019.

3 A hierarchy of risks

Existing datasets constitute a valuable resource for identifying potential trade vulnerabilities. However, it should be recognized that not all trade vulnerabilities pose the same level of risk to the economy. As discussed earlier, different normative arguments justify interventions for enhancing resilience. In this section, we aim to intersect the list of identified trade vulnerabilities with the specific risks they expose the economy to. It is important to note that this analysis is not exhaustive, as many risks are complex and challenging to evaluate based solely on economic criteria. This emphasizes the need for a multidisciplinary approach involving experts from various domains such as industry practitioners, international relations, climate risk analysts, among others. Leveraging diverse expertise can enable the EU to make more informed decisions regarding its vulnerabilities.

3.1 Geopolitical risk

The escalation of geopolitical tensions, notably marked by the Russian invasion of Ukraine, has underscored the significance of geopolitical risks, presenting multifaceted concerns. These risks unfold in two principal ways: firstly, political instability can be a source of disruption in value chains, imposing economic costs on countries reliant upon these networks. A pertinent example is the 2018 US-China trade war, which exposed firms and consumers to substantial price escalations. Secondly, trade interdependencies can be wielded as tools of coercion, limiting countries' capacity to assert independent voices in global discussions. Geopolitical risks are notably prevalent in Africa, where political instability is widespread, yet the continent plays a pivotal role in numerous value chains by being a major source of valuable minerals. However, in several African nations, political volatility and weak governance pose threats to the security of supply chains, leading to potential disruptions.[13] Conversely, mining extraction activities, particularly those of foreign-owned companies, have been linked to heightened conflicts at local levels, exacerbating violence across territories and persisting over time (Berman et al., 2017).[14]

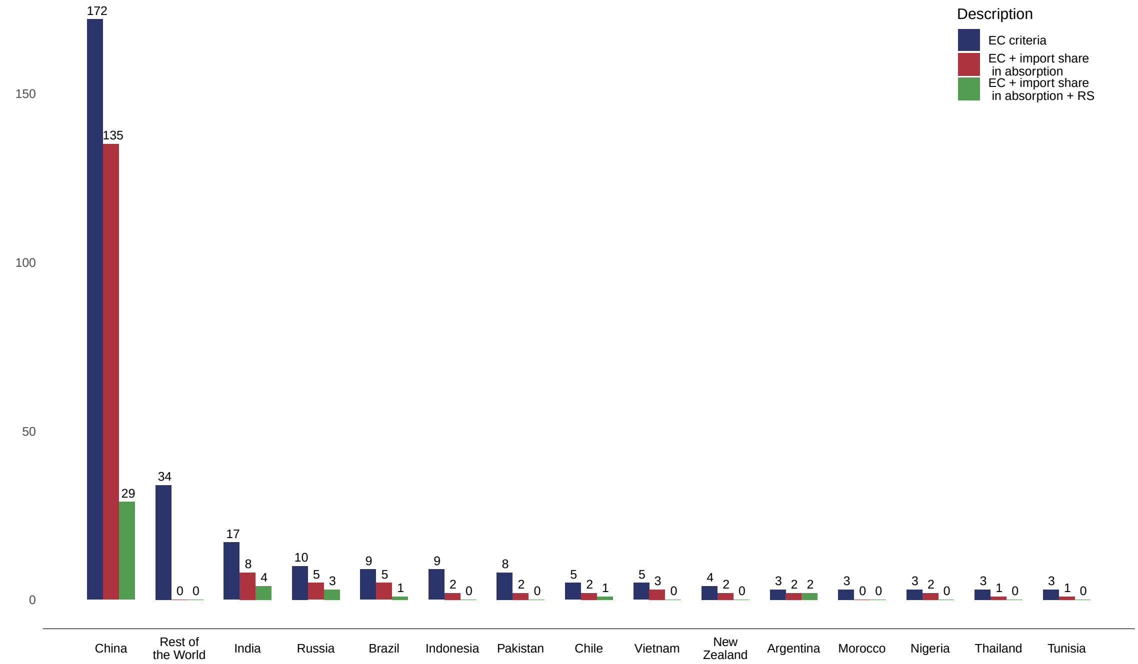
The depiction of the origin of vulnerable products, as identified in Section 2, is illustrated in Figure 3. Further insight into countries outside of NATO is detailed in Figure 5. Out of the 378 (resp. 49) products categorized as strategic dependencies using the EC methodology (resp. the extended EC methodology), 246 (resp. 41) are sourced primarily from countries not affiliated with NATO. China emerges prominently at the forefront of this list, unsurprisingly given its prominent role in global trade.[15] Beyond China, three emerging nations concentrate a notable number of vulnerabilities: India, Russia, and Brazil. Figures B5 and B6 in Appendix B.2 replicates the analysis of direct and indirect firm-level exposures (as displayed in Figure 4), emphasizing French importers engaged in trade with these nations. This analysis confirms that exposure to non-NATO countries significantly impacts trade, with 75% of French extra-EU importers engaging in trade with one of these countries between 2015 and 2019. Moreover, 24% of French importers (resp. 6%) are involved in importing products classified as "vulnerable" based on the baseline (resp. extended) classifications. Here as well, these direct exposures have ripple effects, impacting downstream partners beyond French firms.

[13]See for instance the example of the Democratic Republic of Congo discussed in section 3.4. Weak institutional structures also raise ethical concerns regarding labor practices and the environmental impact of economic activities.

[14]Caselli et al. (2015) have also established the role of resource endowments, such as oilfields, in interstate conflict.

[15]When we cross Figure 3 with the list of our 49 identified strategic dependencies in Table C1, we however show that more than half of the "vulnerable products" that the EU imports from China are final consumption goods. It is unclear whether geopolitical tensions with China that would affect the supply of these final consumption goods is an important threat to European strategic autonomy. We discuss the heterogeneity of risks along the supply chain in Section 3.2. But this example illustrates that the arguments in this section may need to be crossed.

Figure 5: Geographical distribution of trade vulnerabilities among non-NATO countries



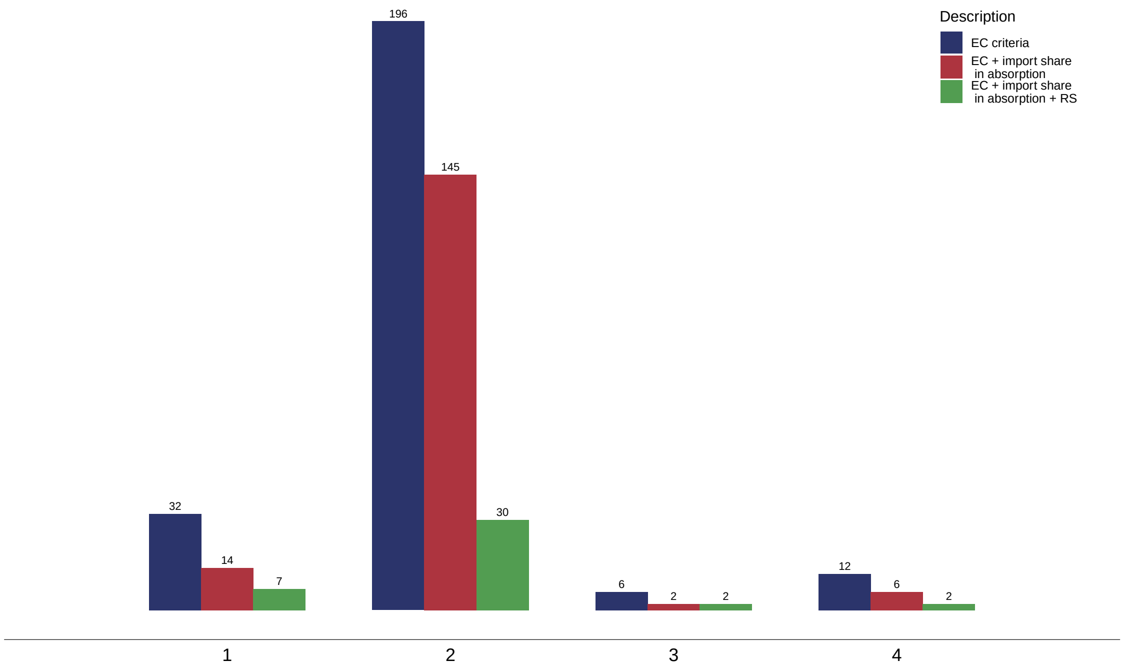
Notes: This figure represents the distribution of non-NATO countries from which the EU imports vulnerable products according to the three methodologies. "Rest of the World" aggregates all remaining countries associated with at least three vulnerable products in the EC methodology. Source: CEPII-BACI and Prodcom for 2015 to 2019.

To enhance the analysis of geopolitical risk, we exploit the country-specific Geopolitical Risk Index (GPR) developed by Caldara and Iacoviello (2022). This index is constructed through a systematic search of country-specific geopolitical events in ten prominent US newspapers.[16] The index captures significant global events, such as the Gulf war, September 11th, terrorist attacks in Europe, or Russian annexion of Crimea in 2014. An important caveat though is that the US-centric search may involve level differences between countries. To ensure comparability, we normalize the GPR indices by a country-specific "norm", represented as the mean level of the index derived from the 200 lowest periods, between January 1985 and June 2023. Averaging these series over 2015-2019 allows us to rank countries based on their levels of geopolitical risk.[17] In Figure 6, we dissect the list of trade vulnerabilities based on the position of the primary sourcing country in the GPR distribution.

[16]The ten newspaper are the Chicago Tribune, the Daily Telegraph, the Financial Times, the Globe and Mail, the Guardian, the Los Angeles Times, the New York Times, USA Today, the Wall Street Journal, and the Washington Post. Examples of the raw time-series are provided in Figure B7 in Appendix B.2.

[17]The database covers only 44 countries. After excluding the 21 NATO countries of these 44 countries, the remaining countries include Argentina, Brazil, Chile, China, Colombia, Egypt, Hong Kong SAR China, Indonesia, India, South Korea, Mexico, Malaysia, Peru, Philippines, Russia, Saudi Arabia, Thailand, Tunisia, Taiwan, Ukraine, Venezuela, Vietnam, and South Africa.

Figure 6: Distribution of trade vulnerabilities by the position of the main sourcing country in the distribution of geopolitical risk



Notes: The list of trade vulnerabilities is restricted to products mostly sourced from non-NATO countries present in the GPR index data. Countries are then ranked according to their position in the distribution of GPR index over 2015-2019. A value of 3 thus indicates that the product is sourced from a country which is in the third quartile of the entire distribution of GPR indices (including all countries for which a GPR index is computed). Source: CEPII-BACI and Prodcom for 2015 to 2019, Caldara and Iacoviello (2022) for the GPR indices.

The majority of trade vulnerabilities concerning non-NATO countries are associated with nations positioned within the lower half of the GPR indices distribution, indicating lower geopolitical risks.[18] Nonetheless, there are 18 (according to the EC methodology) and 4 (according to the extended EC methodology) vulnerable products imported by the EU from non-NATO countries positioned above the median in terms of geopolitical risk. Table C3 in Appendix C.2 details these 18 vulnerable products, among which are the four identified after applying our two criteria on top of the EC methodology.

3.2 Supply chain risk

Supply chain risks refer to the various uncertainties, shocks and disruptions that can occur at any stage of the supply chain process, from sourcing raw materials to delivering finished goods to customers. These risks can arise from various sources, including natural disasters, geopolitical events, economic downturns, technological failures, and changes in regulations or trade policies. The interdependent nature of economic activities within supply chains implies that shocks at one point of the chain spill over to the rest of the chain, thus amplifying the economic cost of the shock. For example, S&P Global Mobility estimates that in 2021 more than 9.5 million units of global light-vehicle production was lost as a direct result of a lack of necessary semiconductors.[19]

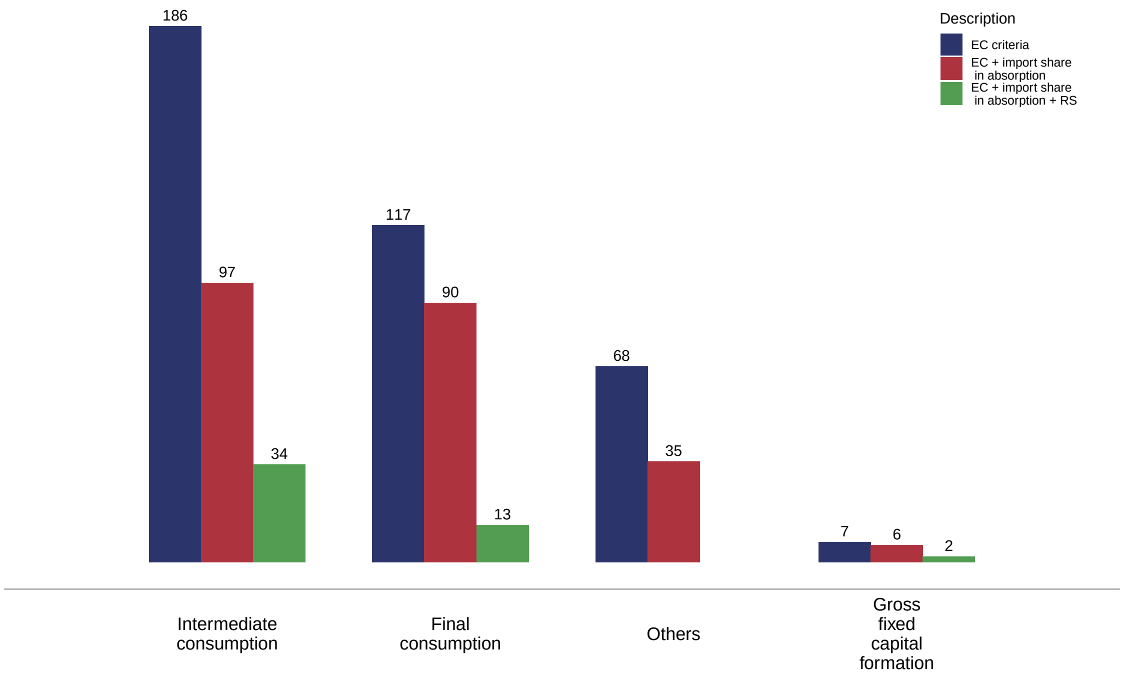
In light of potential cascades within value chains, the resilience of these chains has emerged as a political concern in several developed nations in the aftermath of the Covid-19 pandemic. In their analysis of German vulnerabilities, Baur and Flach (2022) introduce an additional criterion:

[18] This result is a consequence of neither Russia nor China being identified as high geopolitical risk countries based on data for 2015-2019.

[19] https://www.spglobal.com/mobility/en/research-analysis/the-semiconductor-shortage-is-mostly-over-for-the-auto-industry.html

measuring a product's relevance as an input for domestic production. They argue that trade vulnerabilities become more problematic when they jeopardize the competitiveness of domestic firms. To delve deeper into this argument, we initially cross-reference our list of strategic dependencies with their end use within the global value chain, using the Broad Economic Classification (BEC) developed by the United Nations.[20] While disruptions in final consumption goods predominantly affect product availability and prices, shocks to intermediate inputs can cause a ripple effect throughout the production chain. Subsequently, we refine this analysis using the "upstreamness" metric developed by Antras et al. (2012). Using input-output tables, Antras et al. (2012) calculate the average number of stages between the production of a good and its absorption by final consumers, labeling a product as more "upstream" if it enters value chains earlier in the production process. The outcomes are presented in Figures 7 and 8. Additionally, Figures B8 and B9 in Appendix B.2 depict the geographical and sectoral distributions of vulnerable products with an upstreamness measure exceeding three. The most upstream vulnerable products are predominantly imported from China and are concentrated in the energy, mining, basic metals, and chemicals sector.

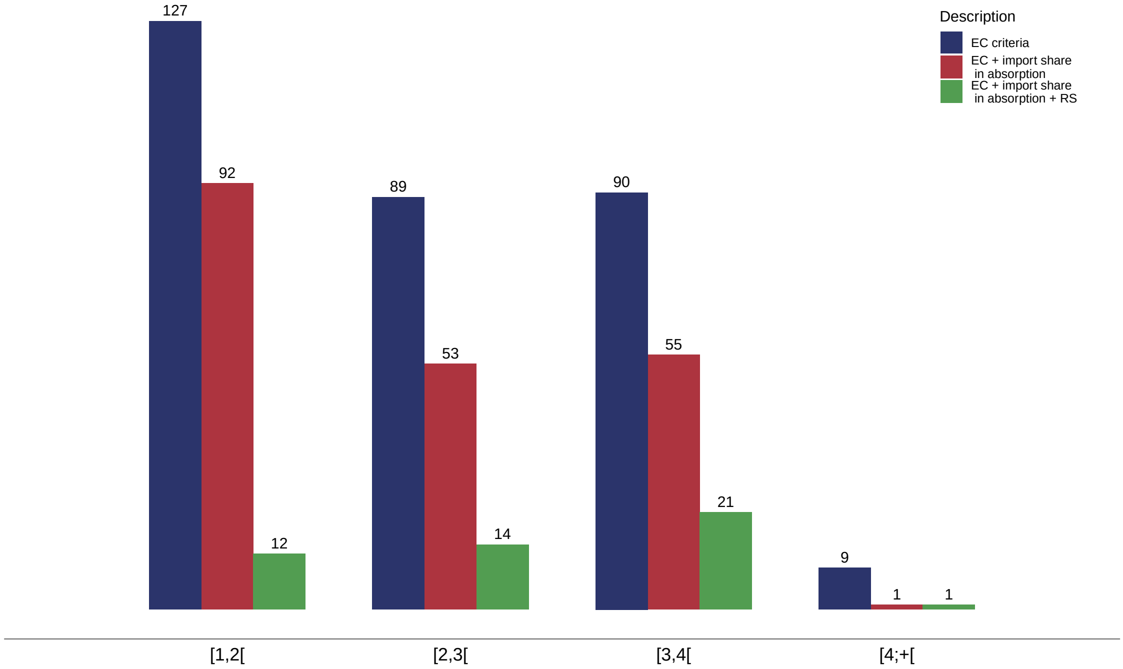
Figure 7: Strategic dependencies, by end use



Notes: The figure illustrates the distribution of identified strategic dependencies, by end use (UN-BEC classification). The blue, red and green bars respectively refer to the EC classification, the classification augmented with the absorption criterion and the classification augmented with the absorption and stickiness criteria. Source: CEPII-BACI and Prodcom for 2015 to 2019.

[20] This classification categorizes HS6 products into eight broad economic categories and further divides them into three end-use categories within the GVCs: intermediate consumption, gross fixed capital formation, and final consumption.

Figure 8: Strategic dependencies, by degree of upstreamness



Notes: The figure illustrates the distribution of identified strategic dependencies, by degree of upstreamness. The value of the upstreamness indicator approximates the number of stages between the production and the absorption by final consumers. An upstreamness of one thus corresponds to a final consumption good while an upstreamness of four indicates that there are four remaining stages before the product enters aggregate demand. See details in Antras et al. (2012). The blue, red and green bars respectively refer to the EC classification, the classification augmented with the absorption criterion and the classification augmented with the absorption and stickiness criteria. Source: CEPII-BACI and Prodcom for 2015 to 2019.

Roughly half of the identified trade vulnerabilities are associated with intermediary products within supply chains (Figure 7). Among these intermediaries, a minority enter value chains at the most upstream level (with an upstreamness value above four), while the rest are positioned two to four stages away from final consumers. Table 2 presents a list of the most upstream vulnerable products identified using our five-criteria method, along with examples of their industrial use. The majority of the most upstream vulnerabilities are related to chemical products. These products often originate from a limited number of countries due to their high degree of customization and significant economies of scale in their production. They serve as inputs across various sectors, including the pharmaceutical industry, plastic product manufacturing, and metallurgy. Consequently, disruptions in these products could potentially impact several sectors aligned with Europe's core comparative advantages.

Table 2: List of the most upstream strategic dependencies

Product	Industrial Use	Upstreamness	Exporter (market share)
Acyclic hydrocarbons	Production of polyethylene	4.20	Russian Federation (70%)
Azelaic acid, sebacic acid, and esters	Skin care, production of nylon and polyester, plasticizers and lubricants in the production of plastics and rubber	3.85	China (81%)
Heterocyclic compounds containing pyrimidine ring	Synthesis of pharmaceuticals, agrochemicals, dyes, and nucleotide analogs (antiviral and anticancer agents)	3.85	China (90%) and India (97%)
Heterocyclic compounds containing piperazine ring	Intermediates in antipsychotic, anti-anxiety drugs, and to treat parasitic worm infections	3.85	China (90%) and India (97%)
Heterocyclic compounds containing malonylurea and its salts	Hypnotic and sedative drugs	3.85	China (90%)
Aromatic monocarboxylic acids and phenylacetic acid	Starting material for the production of pharmaceuticals, perfumes, and flavoring agents	3.85	China (73%)
Trichloroethylene	Industrial solvent and degreasing agent, refrigerants and other hydrofluorocarbons	3.85	USA (90%)
Aldehydes	Resins, organic acides, detergents and soaps	3.85	China (58%)
Oxalic acid, its salts and esters	Mineral processing mechanisms	3.85	China (72%)
Quebracho extract	Natural tannin for processing leather	3.85	Argentina (96%)
Nickel mattes	Extraction and refining of nickel through various metallurgical processes	3.42	Russian Federation (87%)
Unwrought beryllium (powders)	Production of satellite structures and space telescopes, used in nuclear reactors and used military application, medical equipments and nuclear weapons	3.42	USA (62%)
Magnesium (raspings, turnings and granules)	Pyrotechnic compositions and fireworks, reducing agent in the extraction of titanium and zirconium, and used for agriculture, therapeutic applications	3.40	China (91%)
Ferrous products (by direct reduction of iron ore)	Alternative to traditional ironmaking processes such as blast furnace smelting, production of sponge iron	3.36	Russian Federation (60%)
Complex cyanides	Electroplating, metal finishing, gold and silver extraction, pharmaceutical products	3.24	China (75%)
Iodine	Disinfectant and antiseptic, nutrient (thyroid hormones), water purification	3.24	Chile (73%)
Diphosphorus pentoxide	Desiccant and dehydrating agent for pharmaceutical production, glasses	3.24	China (98%)
Phosphinates and phosphonates	Phosphorus for plants, water treatment, metal finishing, detergents, catalysts	3.24	China (83%)
Borax	cleaning agent, pesticide, preservative, fire retardant, antiseptic and anti-inflammatory properties, textile	3.24	
Tungstates (wolframates)	Catalyst, production of thin film materials, pigments, phosphors, ceramics and Glasses	3.24	China (63%)
Silver nitrates	Antiseptic and atibacterial, photographic processing, laboratory reagent, mirror production, antimicrobial properties	3.24	USA (73%)
Castor oil	Laxative, skin care, hair care, anti-Inflammatory, antimicrobial properties, moisturizing lips	3.19	India (98%)

Notes: The table lists the most upstream strategic dependencies, together with examples of industrial uses and their exporter (and respective market shares). The chosen products are those identified as vulnerable based on the augmented EC methodology, with an upstreamness above three. Source: CEPII-BACI and Prodcom for 2015 to 2019.

3.3 Shortage of critical goods

Beyond their economic cost, shortages of critical goods can result in human losses and other severe non-economic consequences. This was vividly illustrated during the early phases of the pandemic when shortages of masks and personal protective equipment compelled policymakers to take drastic measures.[21] An important facet of this problem is the trade-off between the risk linked to often low-probability events and the efficiency of productive systems. As highlighted by Baldwin and Freeman (2021), the assessments of this trade-off might significantly differ between private and social perspectives. This discrepancy underscores the need for public interventions aimed at ensuring a consistent supply of critical goods.

We illustrate this problem using pharmaceutical products as an example. The shortage of pharmaceutical products has emerged as a critical concern in the past two decades. Research conducted by Galdin (2023), drawing on US data, reveals a tenfold increase in drug shortages during the 2000s. Such scarcity prompted the American Medical Association to designate the shortfall of generic drugs as a national security issue in 2018. These shortages predominantly stem from disruptions in the manufacturing process and are primarily confined to generic drugs.[22] Moreover, Galdin (2023) establishes a causal connection between the outsourcing of manufacturing facilities to emerging countries and the occurrence of these shortages.

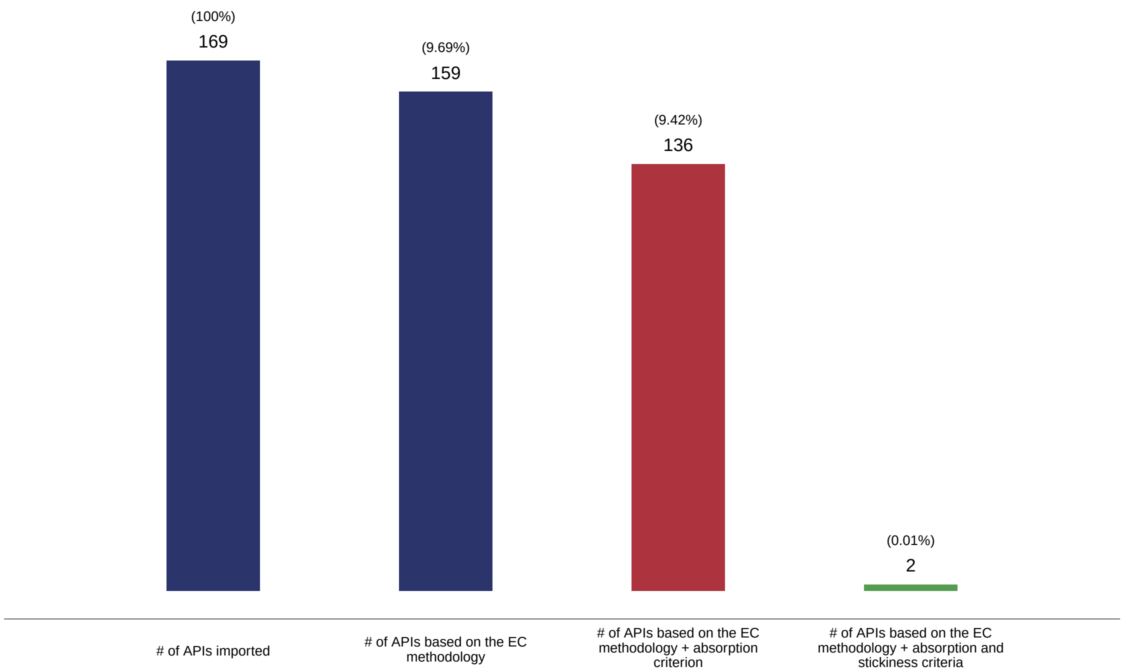
[21] It is important to note the ambiguous role played by international trade in this precise context. While challenges in shipping these products from dominant global production centers contributed to shortages, the rapid expansion of production within these countries also played a pivotal role in meeting the surge in demand. See Figure B12 in Appendix, illustrating the comparison between EU import growth from 2019 to 2020-2021 for all products versus for the HS products identified by the WTO as vital for fighting Covid-19. Trade significantly facilitated the sourcing of Covid-related products, especially in 2020 and 2021. A prime example is the international trade of vaccines, which surged by 700% in 2021 compared to 2019.

[22] See Pauwels et al. (2014) for evidence based on European data. In the European case, generic drugs do not exhibit a notably higher susceptibility to shortages.

A notable characteristic of pharmaceutical products is the precise identification of numerous drugs in trade data through their active pharmaceutical ingredients (APIs), which constitute the essential components imparting therapeutic effects. In Figure 9, we replicate Figure 1, focusing specifically on these API products. The HS nomenclature enables the identification of 170 products by their APIs, linked to 4,497 therapeutic molecules. Among these API products, the EC methodology flags 159 as potential vulnerabilities, a count reduced to 136 when further imposing that the majority of domestic absorption is sourced from abroad. This number diminishes further to just two when concentrating on products presenting difficulties in substitution. When relaxing the stickiness criterion as in Table C2, the number of API products identified as vulnerable increases to 19. The list is provided in Table C5.

While our fifth criterion indicates that API products are not inherently the most challenging to substitute, the absorption criterion underscores a scarcity of EU domestic production for several of these products. This is notable despite the EU maintaining a status as a net exporter of pharmaceutical products.[23] Table C4 in the Appendix C.2 provides a comprehensive list of these products, along with information regarding the diseases they treat and statistics on EU import structures. This list encompasses a broad range of drugs, such as Metharbital, a molecule used in epilepsy treatment, and Daprodustat, utilized in addressing anemias associated with chronic kidney disease. Regarding the geographical distribution of these vulnerabilities, Figure B11 in Appendix B.2 highlights that vulnerable products predominantly originate from Switzerland, Singapore and the US - countries with strong comparative advantages in pharmaceuticals. India and China have also developed large production capacities, particularly in generic products.

Figure 9: Number of "strategic dependencies" and their contribution to aggregate imports, for active pharmaceutical ingredients



Notes: The Figure shows the number of "strategic dependencies" and their contribution to aggregate imports, for active pharmaceutical ingredients when applying the criteria of European Commission (2021) and adding our absorption and stickiness criteria. Source: CEPII-BACI for 2015 to 2019.

[23] It is important to note the sensitivity of these results to the estimation period. When analyzed using data limited to 2019, the absorption criterion appears substantially more restrictive, revealing only three API products from the EC list exhibiting more than 50% of domestic absorption sourced from outside of the EU (Figure B10 in Appendix B.2).

3.4 Green strategic technologies

Until now, our assessment of strategic dependencies was solely based on existing trade data, lacking the forward-looking perspective necessary to anticipate future dependencies. The imperative of decarbonization mandates a profound structural transformation in our economies, with implications for Europe's comparative advantages. None of the trade vulnerabilities identified in section 2 and listed in Table C1 is a direct input for green technologies. This remains true even when applying the less restrictive EC methodology. While this may seem reassuring in light of the European autonomy on these technologies, we still conduct a dedicated analysis in this section. The rational for this is that the structure of European imports over 2015-2019 may be a poor proxy for *future* dependencies in these sectors, given fast expanding production capacities at the worldwide level. In doing this, we thus adjust our statistical approach, focusing on the latest year of (pre-Covid) available trade data in 2019 and digging into the structure of world exports instead of restricting our attention to European imports.

Several studies have delved into the strategic significance of various technologies, both within the EU and the United States. These analyses include technology-specific reports such as those by the US-ITC on Cobalt and Lithium for Lithium-ion Batteries used in Electric Vehicles (Matthews, 2020, LaRocca, 2020, Horowitz et al., 2021) and a comprehensive report by the European Commission on critical raw materials for strategic technologies (European Commission, 2020). Building upon insights from these studies, our focus in this section is on delineating the market landscape, assessing concentration, and identifying key inputs necessary for producing a set of strategic green technologies.

Lithium-ion batteries stand as a pivotal technology in the electrification of the transportation sector, offering substantial energy storage capacity crucial for powering electric vehicles and reducing reliance on fossil fuels. The EU's attainment of its climate objectives hinges significantly on securing access to these batteries. This involves ensuring a consistent supply of vital raw materials such as lithium and cobalt, alongside investments in R&D to enhance the performance and cost-effectiveness of European battery production. Table 3 highlights a relatively modest Hirschman-Herfindahl Index (HHI) for lithium-ion batteries used in EVs, indicating an emerging market with reasonable competition. This represents a strategic opportunity for the EU to become a key player in this sector. However, the high concentration of the cobalt market, primarily dominated by the Democratic Republic of Congo (80% market share, with no exporter other than Austria holding a market share above 5%) raises significant concerns. While less pronounced, future market concentration might become an issue for lithium as well. Lithium carbonates are already identified as vulnerable by the EC methodology in our pooled analysis. Moreover, these resources exhibit low levels of ex-post substitutability, with stickiness indicators above 3 (on a 1-to-4 scale). Given the natural resource constraints on these inputs, proactive diversification of sourcing becomes imperative for the EU.

Table 3: Concentration of worldwide trade for Lithium-ion Batteries for Electric Vehicles and their components

Product ✓ (✓ ✓)	**HHI**	**Top X**	**2nd largest X**	**Nb X MSh > 5%**	**Stickiness**
Lithium-ion Batteries for EV	0.209	China (41%)	Korea (15%)	3	3.02
Cobalt					
Ores and concentrates	0.778	DRC (88%)	Austria (5%)	0	3.49
Oxides and hydroxides (commercial)	0.213	China (32%)	Finland (28%)	4	3.56
Mattes and intermediate products	0.224	DRC (45%)	Canada (8%)	2	3.49
Lithium					
Lithium oxide and hydroxide	0.380	China (59%)	Chile (11%)	3	3.84
Carbonates: lithium carbonate ✓	0.367	Chile (57%)	Argentina (16%)	2	3.16
Alkali or alkali-earth metals	0.192	China (35%)	Russia (15%)	5	3.22
Chlorides	0.0947	China (22%)	Germany (13%)	4	3.37
Fluorides	0.190	China (36%)	Japan (16%)	5	3.88
Mineral substances	0.226	Australia (46%)	China (6%)	2	3.39

Notes: The table details the market structure of Lithium-ion batteries and their main components. The HHI is calculated on world exports, as is the market share of the top and second largest world exporters. The fourth column is the number of exporting countries which world market share is above 5%, beyond the top 2 countries already listed in the previous two columns. The last column is the relationship stickiness measure borrowed from Martin et al. (2020) associated with each product. The red and green checks represent the products identified as vulnerable after applying the absorption (red) and stickiness (green) criteria for this same set of countries. Source: CEPII-BACI for 2019.

Solar panels represent another crucial element in the EU's ambitious goals of reducing greenhouse gas emissions. Their scalability and low operational costs position them as a cost-effective and dependable source of green electricity. The increasing demand and decreasing costs of solar panels have spurred notable technological advancements, resulting in more efficient, durable panels, and innovations in energy storage and grid integration. However, the concentration of global production already limits the EU's capacity for sourcing diversification (Table 4). China is the largest exporter in this sector, with a 43% market share of world exports, followed by Malaysia at 10%. Although less pronounced, the components of solar panels also display high concentration, with China again the main world exporter, although the HHI is low across these markets. This concentration among a small number of countries poses a substantial risk to the solar panel supply chain, potentially leading to shortages and price escalations in case of disruptions in these countries. The risk is all the stronger since these markets display relatively high levels of relationship stickiness.

Table 4: Concentration of worldwide trade for solar panels and their components

Product ✓ (✓ ✓)	**HHI**	**Top X**	**2nd largest X**	**Nb X MSh > 5%**	**Stickiness**
Solar panels	0.216	China (43%)	Malaysia (10%)	4	3.24
Components					
Crystals: mounted piezo-electric	0.145	Japan (28%)	China (19%)	6	2.97
Diodes	0.142	China (32%)	Other Asia (11%)	5	2.73
Parts for diodes, transistors and photosensitive semiconductor devices	0.126	China (24%)	Malaysia (17%)	5	3.26
Photosensitive semiconductor devices	0.0718	USA (15%)	China (13%)	7	2.66
Thyristors, diacs and triacs	0.116	China (27%)	Germany (15%)	3	2.87
Transistors (< 1W dissipation rate)	0.137	China (28%)	Singapore (13%)	7	2.55
Transistors (≥ 1W dissipation rate)	0.110	China (25%)	Germany (11%)	6	2.70

Notes: The table details the market structure of solar panels and their main components. The HHI is calculated on world exports, as is the market share of the top and second largest world exporters. The fourth column is the number of exporting countries which world market share is above 5%, beyond the top 2 countries already listed in the previous two columns. The last column is the relationship stickiness measure borrowed from Martin et al. (2020) associated with each product. The red and green checks represent the products identified as vulnerable after applying the absorption (red) and stickiness (green) criteria for this same set of countries. Source: CEPII-BACI for 2019.

Finally, Table 5 provides an overview of the global trade structure for hydrogen, rare-earth metals, and graphite. Hydrogen, a versatile and clean energy carrier, holds promise across various applications, from fueling cell vehicles to providing electricity and heat for buildings. Its production from diverse sources like water, natural gas, and biomass renders it a flexible, scalable solution for decarbonizing different sectors of the economy. As of now, the hydrogen market is still relatively competitive, with an HHI at 0.264, and dominated by "friend" countries (the Netherlands, followed by Canada). However, hydrogen exhibits high degree of stickiness, which may induce a concentration of the market in the coming years (Table 5).

The second panel of Table 5 presents the world trade structure for rare-earth metals. These metals play pivotal roles in catalysts, glassmaking, metallurgy, and emerging markets such as battery alloys, ceramics and permanent magnets (Charalampides et al., 2015). China currently dominates mining activities, enrichment technologies and metallurgical processes. China is also estimated to represent almost half of the total global mining reserves in rare earth elements. Due to the challenge of diversifying sourcing and limited global resources, the European Parliament adopted a resolution in 2008 on critical raw materials. Among proposed strategies are investments in R&D to enhance recycling and efficient use of critical raw materials, as well as efforts to diversify sourcing, including exploration within European countries like Greece.

The third panel of Table 5 provides an overview of the global trade structure for graphite, encompassing both natural and synthetic forms. Natural graphite is traditionally used in pencils, as a dry lubricant, and in refractories, but is now also used as an input for batteries and brake linings. Synthetic graphite, prized for its high thermal and electrical conductivity, plays a vital role in steel production as electrodes, in lithium-ion batteries for EVs and electronics, and in aerospace components. Its applications extend to fuel cells, heat exchangers, nuclear reactors, and foundries, highlighting graphite's versatility in meeting the demands of modern technology and industry. There is a dominance of China in the export of five out of six graphite products. However, despite this dominance, all these markets still exhibit a high degree of competitiveness, with several alternative export options for artificial graphite. While the structure of supply is still relatively diversified, all these markets display fairly high degree of stickiness. Diversifying sourcing ex-ante is particularly important as a consequence.

Table 5: Concentration of worldwide trade for hydrogen technologies, rare-earth metals, and graphite

Product ✓ (✓ ✓)	**HHI**	**Top X**	**2nd largest X**	**Nb X MSh** $> 5\%$	**Stickiness**
Hydrogen	0.264	Netherlands (38%)	Canada (33%)	1	3.39
Earth-metals, rare ✓✓	0.234	Viet Nam (33%)	China (29%)	3	3.13
Cerium compounds	0.214	Japan (38%)	France (20%)	2	3.20
Compounds, inorganic or organic of rare-earth metals	0.145	China (27%)	Malaysia (18%)	5	3.30
Graphite					
Natural graphite (powder or in flakes)	0.268	China (49%)	Mozambique (12%)	1	3.09
Natural graphite (other forms than powder or in flakes)	0.234	China (46%)	Mozambique (8%)	2	3.51
Artificial graphite	0.160	China (33%)	Japan (15%)	5	2.88
Colloidal or semi-colloidal graphite	0.113	USA (20%)	Netherlands (18%)	6	3.37
Carbonaceous pastes	0.168	China (32%)	Norway (20%)	3	3.08
Graphite or other carbon based preparations	0.215	China (44%)	Mexico (7%)	4	3.15

Notes: The table details the market structure of hydrogen technologies and rare-earth metals. The HHI is calculated on world exports, as is the market share of the top and second largest world exporters. The fourth column is the number of exporting countries which world market share is above 5%, beyond the top 2 countries already listed in the previous two columns. The last column is the relationship stickiness measure borrowed from Martin et al. (2020) associated with each product. The red and green checks represent the products identified as vulnerable after applying the absorption (red) and stickiness (green) criteria for this same set of countries. Source: CEPII-BACI for 2019.

4 Policies in the toolbox

After having developed a methodology to identify potential trade vulnerabilities from existing data in Section 2, we have identified four types of risks associated with trade dependencies in Section 3. The next step involves formulating a policy toolbox to address these vulnerabilities and enhance resilience. This toolbox could encompass various strategies and actions aimed at mitigating risks and building resilience in the face of trade dependencies.

The policy toolbox involves various instruments, many of which intersect with regulatory frameworks, such as article 107 on aids granted by Member States of the Treaty on the Functioning of the European Union. Such subsidies can directly target domestic production capacities or R&D expenses, in which case they are akin to standard industrial policy. They can also take the form of subsidies for firms to invest in resilience. As discussed in US Council of Economic Advisors (n.d.), firm-level resilience investments include "understanding the structure of [...] supply chains (visibility), investing in backup capacity (redundancy), improving their ability to solve problems and substitute between inputs (agility), as well as vertically integrating components of the production process". All of these strategies are costly and potentially subject to sub-optimally low investment as a consequence of network or information externalities.

Information externalities are a salient feature of complex production networks as firms often lack comprehensive insights beyond their immediate supppliers. As argued in Section 2.4, the European Union possesses robust capabilities to aid firms in advancing visibility across supply chains, leveraging extensive datasets encompassing both direct and indirect trade exposures. Enhancing firms' understanding of supply chain risks could be achieved by furnishing statistics that offer detailed insights at a granular level. In selected cases, governmental initiatives could orchestrate sophisticated, real-time data collection initiatives to monitor stock levels across multiple manufacturing entities.[24]

Information regarding potential demand at upstream stages is equally crucial to forecast production capacities, which may be particularly useful in nascent industries. In the 1990s, a US public-private partnership named Sematech successfully orchestrated the development of the semiconductor industry. This initiative facilitated equipment manufacturers to design products that aligned with the requirements of chip designers, fostering collaboration and mutual understanding (US Council of Economic Advisors, n.d.). Coordination efforts can extend to promoting greater harmonization in product design, a strategy that mitigates structural weaknesses within strategic value chains and enhances substitutability among suppliers during disruptions. In the semiconductor industry, Berger et al. (2023) advocates for the adoption of standardized chip architectures, promoting uniformity and transparency across multiple manufacturers. Embracing common design platforms not only reduces heterogeneity but also ensures compatibility with various fabrication facilities, reducing reliance on specific foundries and enhancing supply chain flexibility. Such coordination tools hold significant promise, especially for new products involved in the environmental transition.

Designing policies aimed at addressing network externalities within value chains is complex. Such policies can entail a combination of taxes and subsidies applied to transactions among firms operating in adjacent tiers of the supply chain, as well as incentives to encourage investments in agility and foster supplier relationships (Grossman et al., 2023). However, crafting the optimal structure for these tax and subsidy frameworks hinges on assessing firms' bargaining power across the chain and the substitutability among different inputs — factors that are challenging to quantify effectively. Under reasonable assumptions regarding the degree of substitutability between inputs along the value chain, Grossman et al. (2023) show that optimal subsidies for resilience tend to diminish as goods progress dowstream. This implies that government intervention might be more critical in industries supplying inputs across numerous individual supply chains, as detailed in Section 3.2.

In critical sectors, the public may be willing to bear a higher cost for achieving a socially optimal level of resilience. This involves government focus on industries that play a pivotal role

[24] A notable example of such an information system is observed in France for certain drugs classified as critical medicine, as detailed in https://ansm.sante.fr/page/informations-relatives-au-decret-ndeg-2021-349-du-30-03-2021.

in national security (Section 3.3). Such interventions often manifest as investments in domestic production capabilities or the creation of stockpiles. Many countries thus maintain substantial "strategic reserves" of essentials like food, pharmaceuticals or defense resources due to the steep consequences of insufficient supply (Baldwin and Freeman, 2021). Defining the boundaries of national security presents a primary challenge. While today's national security remains a significant concern, particularly amid the current global landscape marked by geopolitical risks, it is crucial to also consider future national security needs. This necessitates substantial investments in green technologies to ensure resilience in times ahead.

While subsidies to bolster domestic production capacities are not the sole tool in the resilience toolkit, public discussions surrounding resilience have predominantly advocated for their implementation. Increasing domestic production has the potential to enhance the agility of production processes, by minimizing transportation durations and foestering improved communication. Additionally, targeting domestic production in sectors where local absorption heavily relies on foreign products is a mechanical way of improving overall risk diversification (Section 2.2).[25] The rational for a renewal of industrial policy becomes particularly evident for green technologies. Protecting nascent industries can justify subsidizing domestic production, even though continued diversification of foreign sourcing remains imperative for certain natural resources (Section 3.4). This diversification can be supported through standard trade policy tools, especially in cases where there are alternative suppliers in the market. The Canadian government has thus implemented a strategy to strengthen Canada's position across the entire value chain of critical raw materials, including mining, manufacturing, and recycling (Government of Canada, 2022). Such an initiative positions Canada as a credible and geopolitically low-risk alternative supplier for raw materials, that European producers could exploit in the future. Beyond diversifying suppliers, strategies can target the technologies used in green strategic technologies. For instance, specific types of electric vehicle batteries are evolving independently from materials like lithium or cobalt, thereby reducing reliance on these increasingly concentrated markets. The new NMC 811 batteries thus have a very low manganese and cobalt content, while sodium-ion batteries are currently being developed by Northvolt.[26]

While targeted industrial policy supported by public investment holds clear economic justification, the institutional context involves an additional difficulty. Industrial policy is a competence of Member States, yet investments in resilience serve as a public good that benefits the entire EU. Therefore, coordinating resilience investments at the European level becomes imperative to avoid a potential subsidy war that could exacerbate prevailing imbalances between Member States. The spatial distribution of public investments should also achieve a balance between strengthening existing industrial clusters to maximize vertical spillovers, thereby reinforcing manufacturing comparative advantages in countries that currently exhibit substantial current account surpluses, and reinvigorating regions that have experienced declines in manufacturing employment and could benefit from the structural transformation driven by the environmental transition. At the European scale, a more comprehensive understanding of this equilibrium is attainable compared to policies enacted at the individual Member State level, which address similar balances locally without fully considering the implications of these decisions on other member States.

[25] However, over-reliance on domestic production might also pose vulnerabilities as international trade plays a vital role in risk sharing.

[26] See details in https://northvolt.com/articles/northvolt-sodium-ion/

5 Conclusion

In this Chapter, we contribute to the recent literature focusing on data-driven methodologies for identifying strategic dependencies using product-level trade data. The European Commission (EC) has proposed a "bottom-up" approach to identify strategic products primarily imported from dominant countries and concentrated markets. While acknowledging the significance of concentrated foreign input sourcing as a vulnerability, a comprehensive vulnerability assessment should also consider the potential for substituting disrupted input sources, both domestically and abroad. We thus, enhance the EC's strategy by introducing two new criteria that account for these substitution sources and by explicitely incorporating product-level domestic production data in the vulnerability methodology. In addition to the EC's three criteria, we identify a product as vulnerable if over 50% of domestic absorption originates from foreign sources and if the ex-post substitutability of a product is in the 25% lowest of the product distribution.

We use the CEPII-BACI and EUROSTAT-PRODCOM databases, which respectively cover worldwide bilateral trade flows and European production at a detailed 6-digit product level. The focus of the analysis is on the European Union and we thus consolidate all data across the 27 member states of the European Union. Our analysis accounts for the inherent volatility in trade flows by pooling data over five consecutive years (2015 to 2019). Following the EC's three criteria methodology, we identify 378 products (out of 5,381) as "strategic dependencies". An additional "absorption" criterion reduces the set of vulnerabilities to 228 products, by disregarding product markets for which at least 50% of European absorption is sourced from domestic firms. Finally, we further restrict attention to 49 products displaying high level of stickiness, in which ex-post substitution away from disrupted inputs is likely to be difficult. These 49 products account for 0.5% of the total value of the EU's aggregate imports. Considering the potential for both domestic and foreign substitution not only substantially refines the EC's list but also modifies the sectoral distribution of these dependencies. We discuss how the EU could leverage upon already collected data to improve our understanding of European production capabilities and indirect exposure to trade.

Existing data serves as a valuable resource for identifying potential trade vulnerabilities. However, not all trade vulnerabilities expose the economy to the same level of risk. Several normative arguments justify interventions for enhancing resilience. We analyze our list of vulnerable products through the lens of four (non-mutually exclusive) risks. We first discuss geopolitical risk by focusing on vulnerable products sourced from non-NATO countries (41 products). The potential risk for the economy in the event of geopolitical tensions, and the designed resilience policies, should also take into account the estimated cost of such a disruption, as well as the end use and relevance of the product in the value chain. To this aim, we link the list of vulnerable products to a measure of upstreamness in the value chain. We identify 22 upstream inputs that expose the EU to supply chain risks. Beyond the economic cost of supply chain disruptions, shortages of critical goods can result in human losses and other severe non-economic consequences. We illustrate this using pharmaceutical products as an example. In this sector, trade dependencies are however limited due to large European production capabilities and a low degree of stickiness for active principal ingredients. Finally, we conclude the analysis with a focus on a selected sample of green products (Cobalt, Lithium, rare earth-metals, and graphite) and renewable strategic technologies (Lithium-ion batteries for electric vehicles, solar panels, and hydrogen). These are not yet identified as vulnerable, but due to their market characteristics, are expected to be if the EU is not able to secure the necessary inputs. This is especially critical given that several of these technologies depend on rare resources, often concentrated among a handful of suppliers outside the EU, with very low potential for ex-post substitutability.

Finally, we discuss resilience policies that governments could employ. A main argument of this paper is the relevance of supplier diversification (especially towards geopolitically stable countries) and domestic production to offset imported risks from non-EU sources. Subsidies to bolster domestic production, particularly in sectors heavily reliant on foreign products, can improve overall risk diversification and the EU's position in value chains. The case for such industrial policy is particularly strong in green industries. However, the coordination of these subsidies, which is a competence of Member States, is essential to avoid potential subsidy wars and address imbalances among Member States. The spatial distribution of public investments aims to strike a balance between reinforcing existing industrial clusters and revitalizing regions experiencing declines in manufacturing employment. Additionally, there are alternative strategies such as investment in alternative technologies, standardization of production processes to facilitate substitutability, and the establishment of real-time monitoring of stocks.

References

Antras, Pol, Davin Chor, Thibault Fally, and Russell Hillberry, "Measuring the Upstreamness of Production and Trade Flows," *American Economic Review*, May 2012, *102* (3), 412–416.

Antràs, Pol and Davin Chor, "Global Value Chains," NBER Working Papers 28549, National Bureau of Economic Research, Inc March 2021.

Backus, David K, Patrick J Kehoe, and Finn E Kydland, "International Real Business Cycles," *Journal of Political Economy*, August 1992, *100* (4), 745–775.

Baldwin, Richard and Rebecca Freeman, "Risks and global supply chains: What we know and what we need to know," NBER Working Papers 29444, National Bureau of Economic Research, Inc October 2021.

Baur, A. and L. Flach, "German-Chinese Trade Relations: How Dependent is the German Economy on China?," EconPol Policy Report 6, CESifo 2022.

Berger, Abigail, Hassan Khan, Andrew Schrank, and Erica R. H. Fuchs, "A New Policy Toolbox for Semiconductor Supply Chains," *Issues in Science and Technology*, Summer 2023, *39* (4), 39–42.

Berman, Nicolas, Mathieu Couttenier, Dominic Rohner, and Mathias Thoenig, "This Mine Is Mine! How Minerals Fuel Conflicts in Africa," *American Economic Review*, June 2017, *107* (6), 1564–1610.

Boehm, Christoph E., Aaron Flaaen, and Nitya Pandalai-Nayar, "Input Linkages and the Transmission of Shocks: Firm-Level Evidence from the 2011 Tōhoku Earthquake," *The Review of Economics and Statistics*, March 2019, *101* (1), 60–75.

Bonadio, Barthélémy, Zhen Huo, Andrei A. Levchenko, and Nitya Pandalai-Nayar, "Global supply chains in the pandemic," *Journal of International Economics*, 2021, *133* (C).

Bonneau, C. and M. Nakaa, "Vulnérabilité des approvisionnements français et européens," Trésor-Éco 274, French Treasury 2020.

Bui, Ha, Zhen Huo, Andrei A. Levchenko, and Nitya Pandalai-Nayar, "Information Frictions and News Media in Global Value Chains," NBER Working Papers 30033, National Bureau of Economic Research, Inc May 2022.

Caldara, Dario and Matteo Iacoviello, "Measuring Geopolitical Risk," *American Economic Review*, April 2022, *112* (4), 1194–1225.

Caselli, Francesco, Massimo Morelli, and Dominic Rohner, "The Geography of Interstate Resource Wars," *The Quarterly Journal of Economics*, 2015, *130* (1), 267–315.

_ **, Miklós Koren, Milan Lisicky, and Silvana Tenreyro**, "Diversification Through Trade," *The Quarterly Journal of Economics*, 2020, *135* (1), 449–502.

Charalampides, Georgios, Konstantinos Vatalis, Baklavaridis Apostoplos, and Benetis Ploutarch-Nikolas, "Rare Earth Elements: Industrial Applications and Economic Dependency of Europe," *Procedia Economics and Finance*, 2015, *24*, 126–135.

Cravino, Javier and Andrei A. Levchenko, "Multinational Firms and International Business Cycle Transmission," *The Quarterly Journal of Economics*, 2017, *132* (2), 921–962.

Dhyne, Emmanuel, Ayumu Ken Kikkawa, Magne Mogstad, and Felix Tintelnot, "Trade and Domestic Production Networks," *The Review of Economic Studies*, 10 2020, *88* (2), 643–668.

di Giovanni, Julian and Andrei A. Levchenko, "Putting the Parts Together: Trade, Vertical Linkages, and Business Cycle Comovement," *American Economic Journal: Macroeconomics*, April 2010, *2* (2), 95–124.

_ and _ , "Country Size, International Trade, and Aggregate Fluctuations in Granular Economies," *Journal of Political Economy*, 2012, *120* (6), 1083–1132.

_ , _ , and Isabelle Mejean, "The Micro Origins of International Business-Cycle Comovement," *American Economic Review*, January 2018, *108* (1), 82–108.

_ , _ , and _ , "Foreign Shocks as Granular Fluctuations," NBER Working Papers 28123, National Bureau of Economic Research, Inc November 2020.

Elliott, Matthew, Benjamin Golub, and Matthew V. Leduc, "Supply Network Formation and Fragility," *American Economic Review*, August 2022, *112* (8), 2701–2747.

European Commission, "Critical Raw Materials for Strategic Technologies and Sectors in the EU," Technical Report, European Commission 2020.

_ , "Strategic dependencies and capacities," Commission Staff Working Document, European Commission May 2021.

Frankel, Jeffrey A and Andrew K Rose, "The Endogeneity of the Optimum Currency Area Criteria," *Economic Journal*, July 1998, *108* (449), 1009–1025.

Galdin, Anais, "Resilience of Global Supply Chains and Generic Drug Shortages," 2023.

Government of Canada, "The Canadian Critical Minerals StrategyEU from exploration to recycling: Powering the Green and Digital Economy for Canada and the World," Technical Report, Government of Canada 2022.

Grossman, Gene M., Elhanan Helpman, and Alejandra Sabal, "Resilience in Vertical Supply Chains," 2023.

_ , _ , and Hugo Lhuillier, "Supply Chain Resilience: Should Policy Promote Diversification or Reshoring?," NBER Working Papers 29330, National Bureau of Economic Research, Inc October 2021.

Horowitz, Jeff, David Coffin, and Brennan Taylor, "Supply Chain for E.V. Batteries: 2020 Trade and Value-added update," Office of Industries, Working Paper 072, US ITC 2021.

Jaravel, Xavier and Isabelle Mejean, "A data-driven resilience strategy in a globalized world," Notes du CAE, Conseil d'Analyse Economique April 2021.

Kleinert, Jörn, Julien Martin, and Farid Toubal, "The Few Leading the Many: Foreign Affiliates and Business Cycle Comovement," *American Economic Journal: Macroeconomics*, October 2015, *7* (4), 134–159.

Lafrogne-Joussier, Raphael, Julien Martin, and Isabelle Mejean, "Supply Shocks in Supply Chains: Evidence from the Early Lockdown in China," *IMF Economic Review*, March 2023, *71* (1), 170–215.

LaRocca, Gregory, "Global Value Chains: Lithium in Lithium-ion Batteries for Electrical Vehicles," Office of Industries, Working Paper 069, US ITC 2020.

Martin, Julien, Isabelle Mejean, and Mathieu Parenti, "Relationship stickiness, international trade, and economic uncertainty," CEPR Discussion Papers 15609, C.E.P.R. Discussion Papers December 2020.

Matthews, Daniel, "Global Value Chains: Cobalt in Lithium-ion Batteries for Electrical Vehicles," Office of Industries, Working Paper 067, US ITC May 2020.

Moll, Benjamin, Moritz Schularick, and Georg Zachmann, "The power of substitution. The Great German Gas Debate in Retrospect," *Brooking Papers on Economic Activity*, 2023.

OECD, "Fostering Economic Resilience in a World of Open and Integrated Markets: Risks, Vulnerabilities and Areas for Policy Action," Report prepared for the 2021 UK presidency of the G7, OECD 2021.

Pauwels, Kim, Huys Isabelle, Casteels Minne, and Simoens Steven, "Drug shortages in European countries: a trade-off between market attractiveness and cost containment ?," *BMC Health Services Research*, 2014, *14* (438).

Thoenig, M., "Trade Policy in the Shadow of War: Quantitative Tools for Geoeconomics," CEPR Working Paper, CEPR 2023.

US Council of Economic Advisors, Technical Report.

Vicard, V. and P. Wibaux, "EU Strategic Dependencies: A Long View," Policy Brief, OECD 2023.

White House, The, "Building resilient supply chains, revitalizing American manufacturing, and fostering broad-based growth," 100-Day Reviews under Executive Order 14017, The White House 2021.

A Data Appendix

A.1 Data on domestic production

Eurostat's Prodcom database facilitates the connection between trade and production data, albeit with some caveats. First, the matching of Prodcom codes with the HS nomenclature is not perfect. Second, the Prodcom database contains a significant number of missing values or zeros. The nature of these missing values remains unclear, whether indicating the absence of product-level production capacities in the respective country or poor data quality due to insufficient coverage, misreporting, or other issues.

Focusing on production data reported for the years 2015 to 2019 by the 27 EU countries, we identify 4,248 Prodcom products in the database and 510,836 potential data points. Among these observations, 21% have missing output, 48% are zeros, and 31% correspond to strictly positive output values. On average, for each Prodcom product, 31% of the filled observations are neither zeros nor missing, 49% are zeros, and 20% are missing. These characteristics remain constant over time (as analyzed individually for 2015, 2016, 2017, 2018, and 2020). Despite the crucial role of this dataset in identifying European strategic vulnerabilities, the quality of the data is a source of concern and results should thus be interpreted with caution.

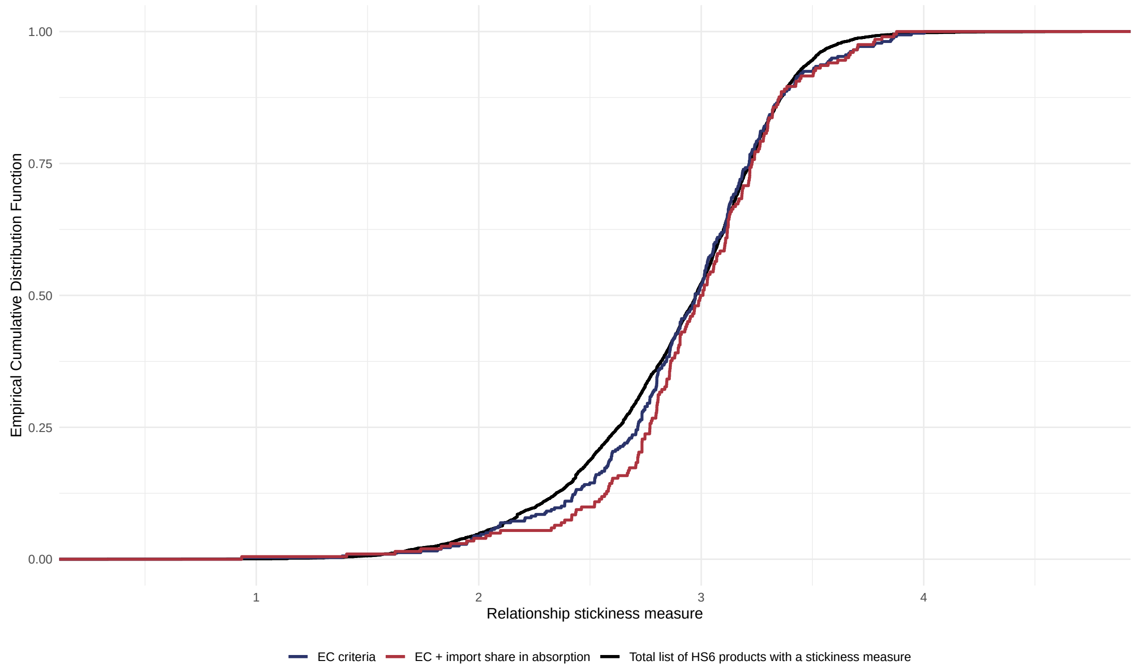
Out of the 378 HS6 products identified as vulnerable using the EC methodlogy, only 336 have an equivalence with Prodcom codes, and 326 are effectively matched with Prodcom from 2015 to 2019. All of these products display some zero production observations, and 325 have missing ones. Among the 326 HS6 products matched with Prodcom, 161 correspond to a one-to-one matching between HS6 and Prodcom codes. 16 HS6 codes are matched with multiple prodcom products while 129 HS6 codes display many-to-one matching. Finally, 27 HS6 codes correspond to many-to-many matches. For the absorption criteria analysis, we need to consolidate production data across EU countries. To do this, we exclude the many-to-many matches (27 HS6 products), leaving us with 306 HS6 products for which we can calculate absorption. Finally, only 4 HS6 codes among these 306 HS6 products have a negative absorption due to production data quality issues. Therefore, we exclude these 4 HS6 products from our list of 306 HS6 products, leaving us with 302 products for which we compute absorption.

This absorption calculation is carried out as follows. For the 161 HS6 products linked to 161 Prodcom products, we compute the consolidated extra-EU import and export flows, for each product and year, using the CEPII's BACI database, and average over time. Simultaneously, we calculate the consolidated EU production, by product and year, excluding missing values and zeros, and average over time. Finally, we merge both datasets to calculate absorption and the contribution of foreign products to domestic absorption. In instances in which the relationship involves an HS6 product merged with multiple Prodcom products, production is consolidated across Prodcom codes, within each HS6 product. When the relationship involves many-to-one matching from HS6 to Prodcom, the trade data are consolidated across HS6 codes within each Prodcom product.

B Additional Figures

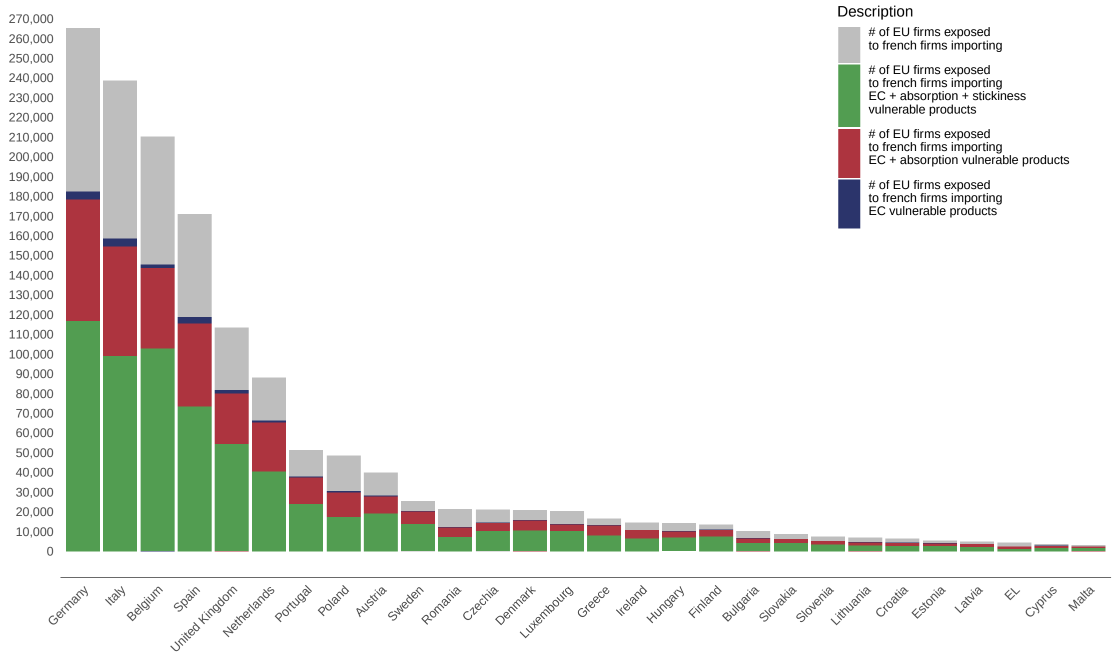
B.1 A diagnosis of trade vulnerabilities

Figure B1: Cumulative distribution function of the measure of stickiness, in the entire distribution and in the list of strategic dependencies identified by the European Commission and after adding the absorption criterion



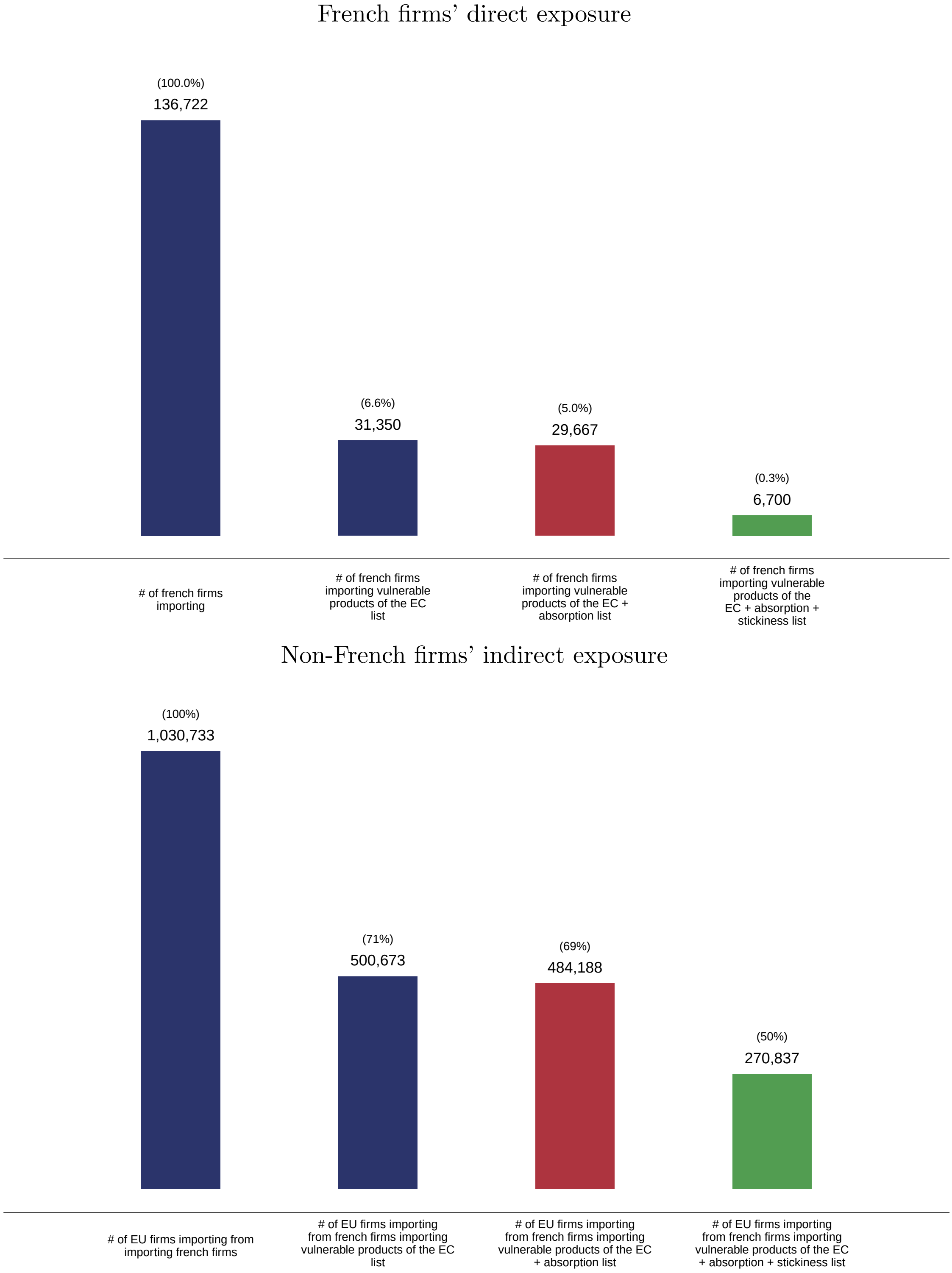
Notes: The figure shows the cumulated distribution of relationship stickiness indicators. The black line is in the overall list of HS6 products, the blue line is restricted to vulnerable products identified using the EC baseline methodology, the red line is in the list further restricted with the absorption criterion. Source: Martin et al. (2020) for the relationship stickiness measure.

Figure B2: Geographical distribution of the number of firms indirectly exposed to vulnerable products through their interaction with French firms



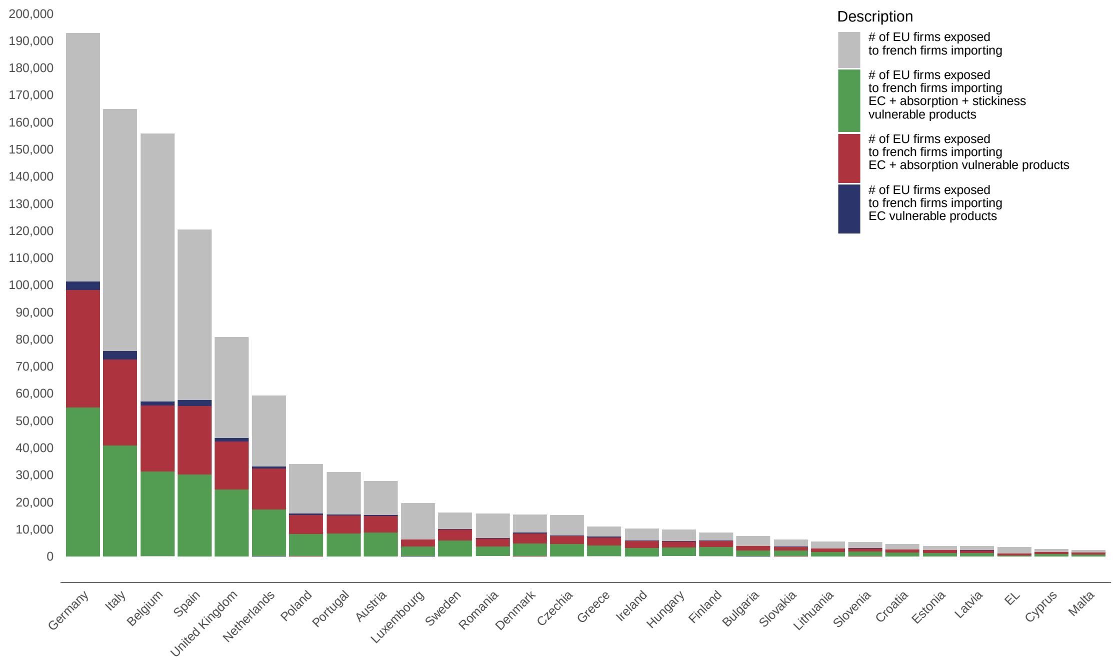
Notes: The figure shows, for each EU country, the number of firms connected with French importers through their own imports (grey bars), and the number of firms indirectly exposed to vulnerable products through these interactions (blue, red and green bars using increasingly restrictive definitions of vulnerable products). Source: French Customs data for 2015 to 2019.

Figure B3: Indirect exposure to strategic dependencies, through firm-to-firm trade when excluding French wholesalers



Notes: The top panel presents statistics on the number of non-wholesaler, French firms and their contribution to French imports from non-EU countries, that are exposed to EU trade dependencies, through their imports. The bottom panel shows statistics on European firms that are indirectly exposed, through their interactions with French exposed importers. The top panel uses customs data on firm-level extra-EU imports. The bottom panel uses customs data on firm-to-firm intra-EU exports. A firm is considered directly exposed if it imports at least one product which is classified as a strategic dependency. A firm is considered indirectly exposed if it imports from a French firm that is directly exposed. Source: French Customs data for 2015 to 2019.

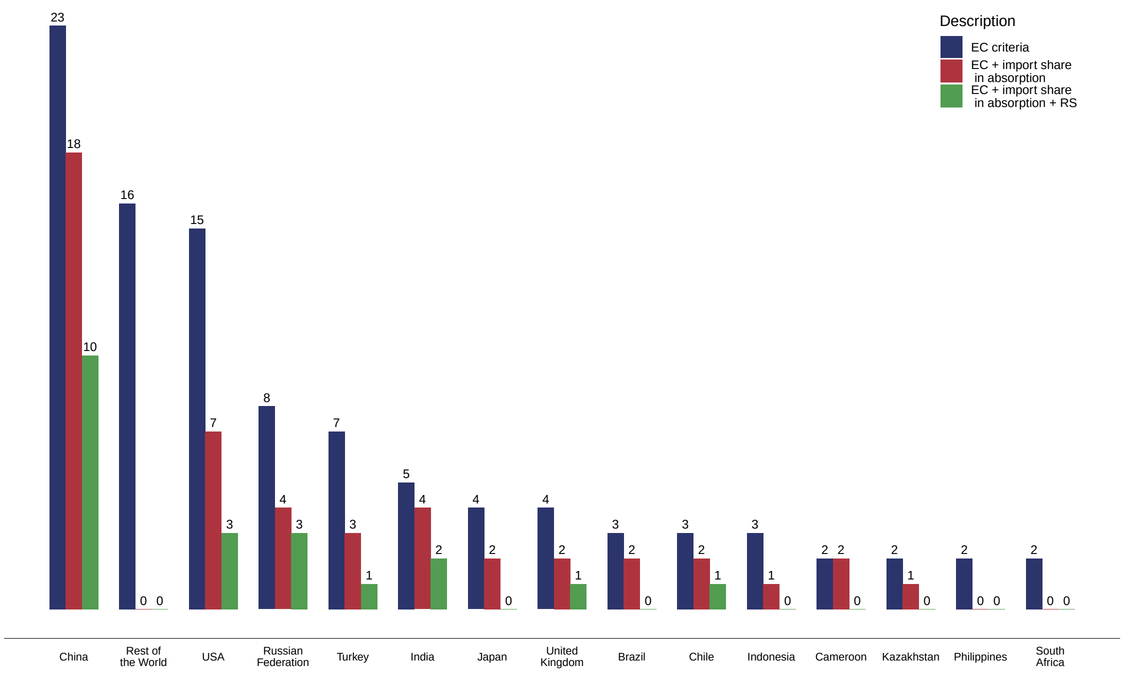
Figure B4: Geographical distribution of the number of firms indirectly exposed to exposed to vulnerable products through their interaction with French non-wholesaler importers



The figure shows, for each EU country, the number of firms connected with French importers through their own imports (grey bars), and the number of firms indirectly exposed to vulnerable products through these interactions (blue, red and green bars using increasingly restrictive definitions of vulnerable products). French importers in the wholesale sector are excluded. Source: French Customs data for 2015 to 2019.

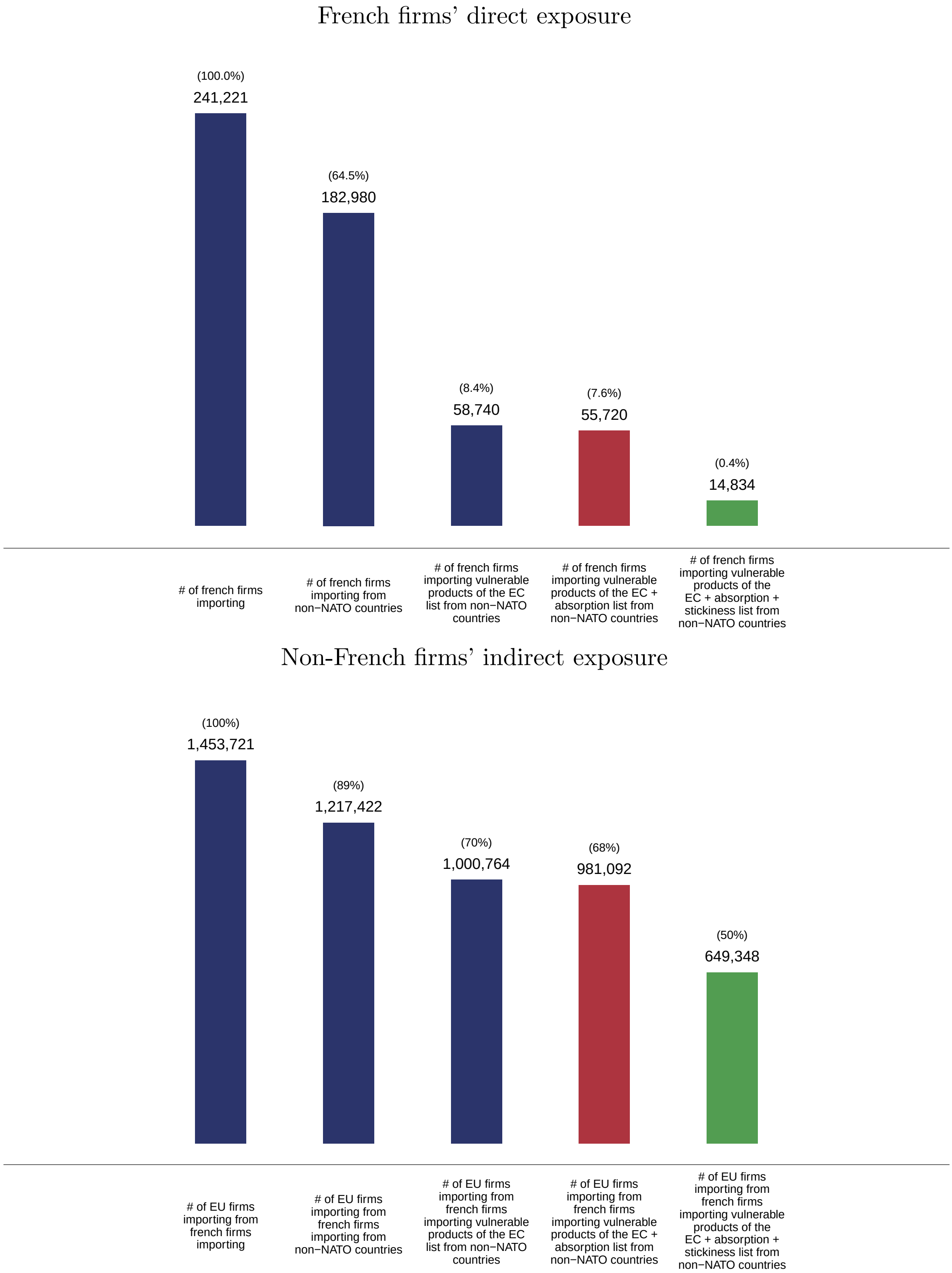
B.2 A hierarchy of risks

Figure B8: Geographical distribution of the most upstream vulnerable products



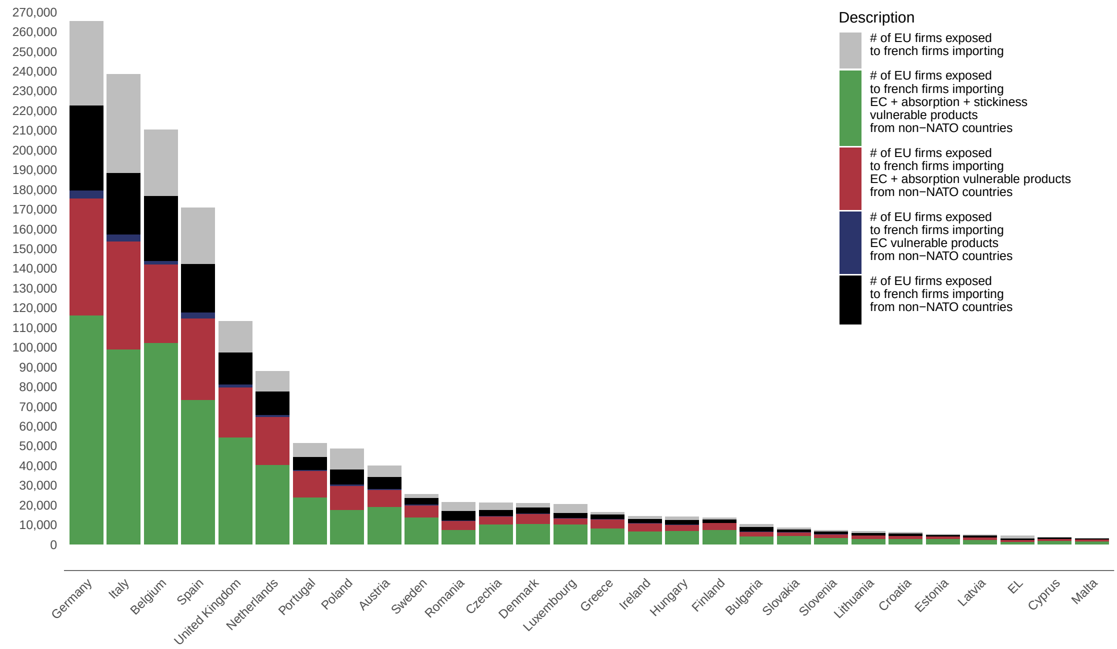
Note: The figure shows the number of vulnerable products with an upstreamness measure above three, by country of origin. Source: CEPII-BACI and Prodcom for 2015 to 2019.

Figure B5: Indirect exposure to strategic dependencies vis-à-vis non-NATO countries, through firm-to-firm trade



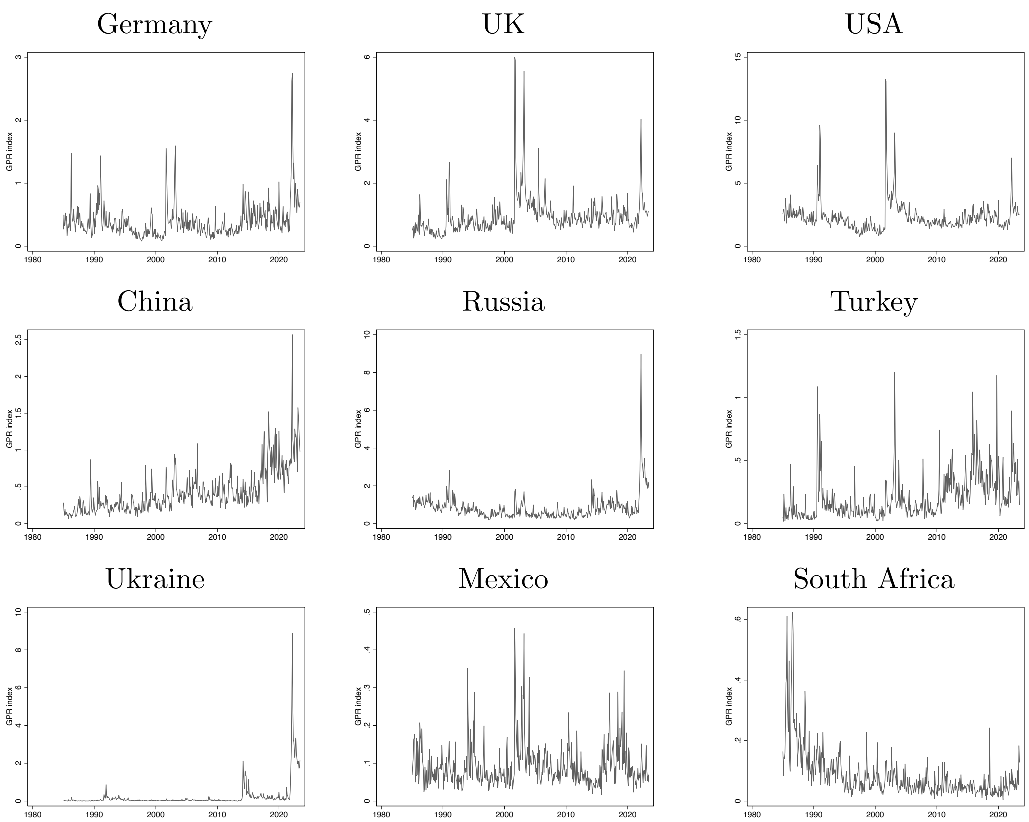
Notes: The top panel presents statistics on the number of firms (and their contribution to French extra-EU imports) that are exposed to EU trade dependencies vis-à-vis non-NATO countries, through their imports. The bottom panel shows statistics on firms that are indirectly exposed, through their interactions with French exposed importers. The top panel uses customs data on firm-level extra-EU imports. The bottom panel uses customs data on firm-to-firm intra-EU exports. A firm is considered directly exposed if it imports at least one product which is classified as a strategic dependency. A firm is considered indirectly exposed if it imports from a French firm that is directly exposed. Source: French Customs for 2015 to 2019.

Figure B6: Geographical distribution of the number of firms indirectly exposed to vulnerable products sourced from non-NATO countries through their interaction with French importers



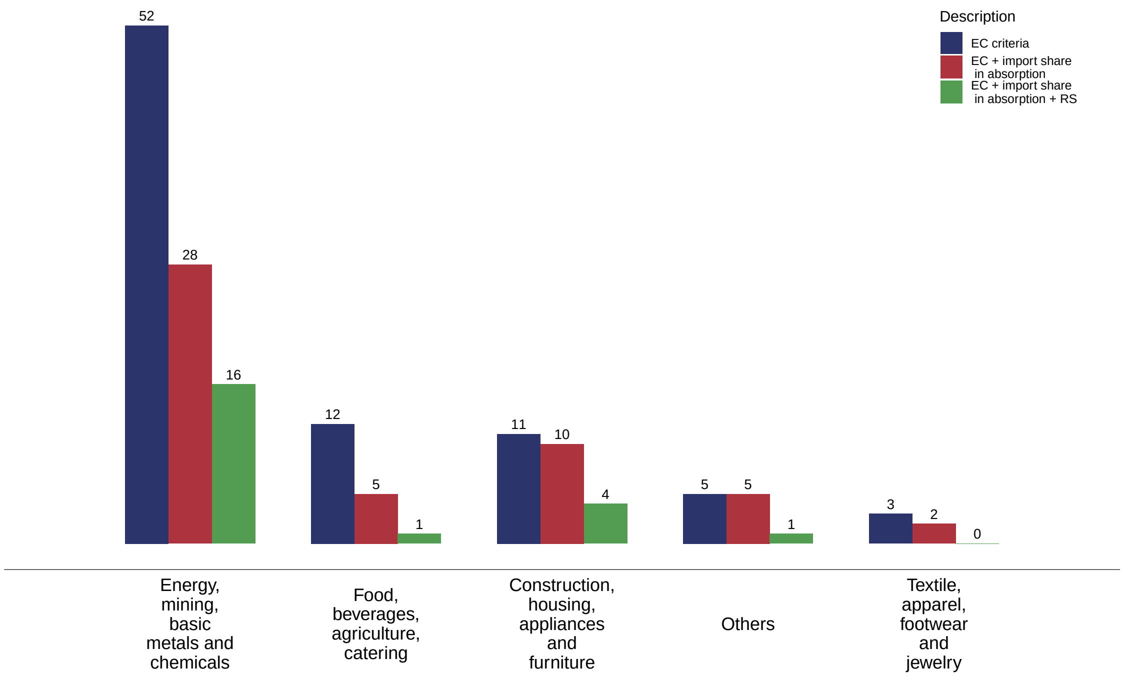
Notes: The figure shows the geographical distribution of indirect trade exposures among European firms importing from French importers of vulnerable products from Non-NATO countries. Source: French Customs for 2015 to 2019.

Figure B7: GPR indices, raw data



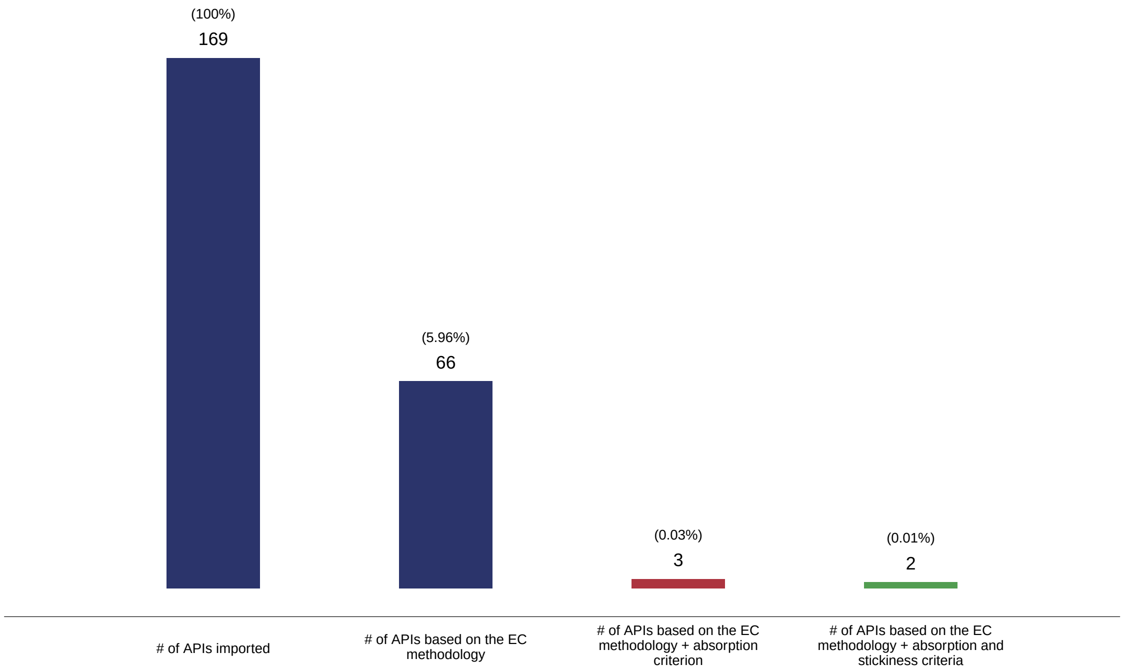
Notes: The figure shows time-series of the GPR index constructed in Caldara and Iacoviello (2022).

Figure B9: Sectoral distribution of the most upstream vulnerable products



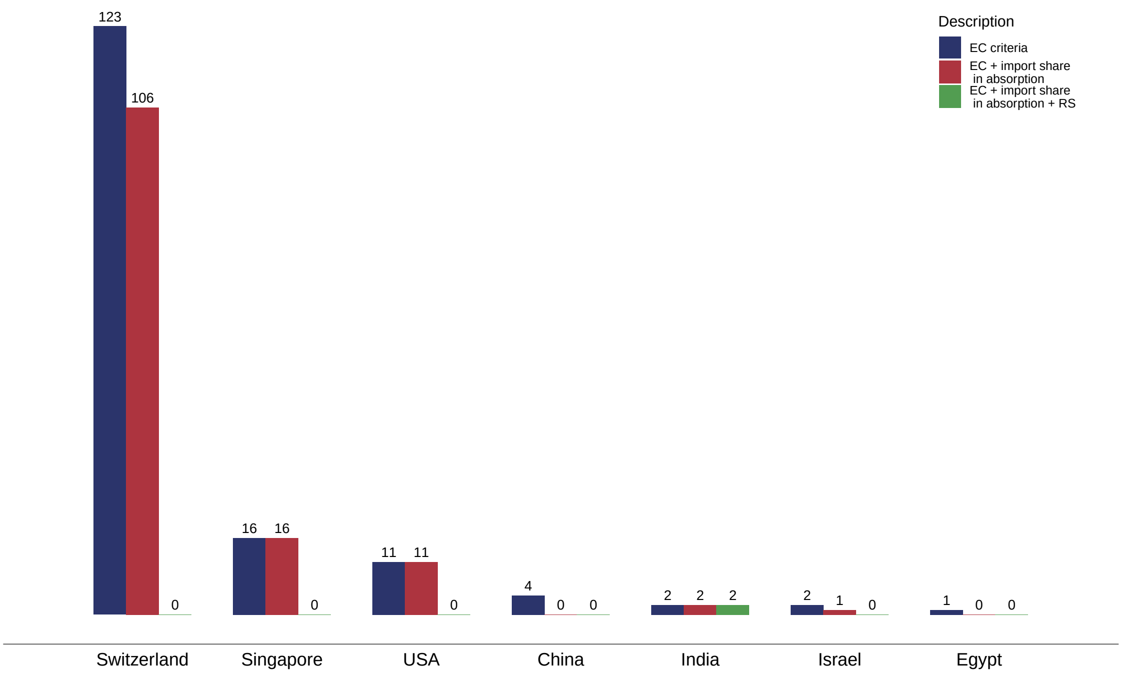
Note: The figure shows the number of vulnerable products with an upstreamness measure above three, by UN-BEC sector. Source: CEPII-BACI and Prodcom for 2015 to 2019.

Figure B10: Number of "strategic dependencies" and their contribution to aggregate imports, for active pharmaceutical ingredients



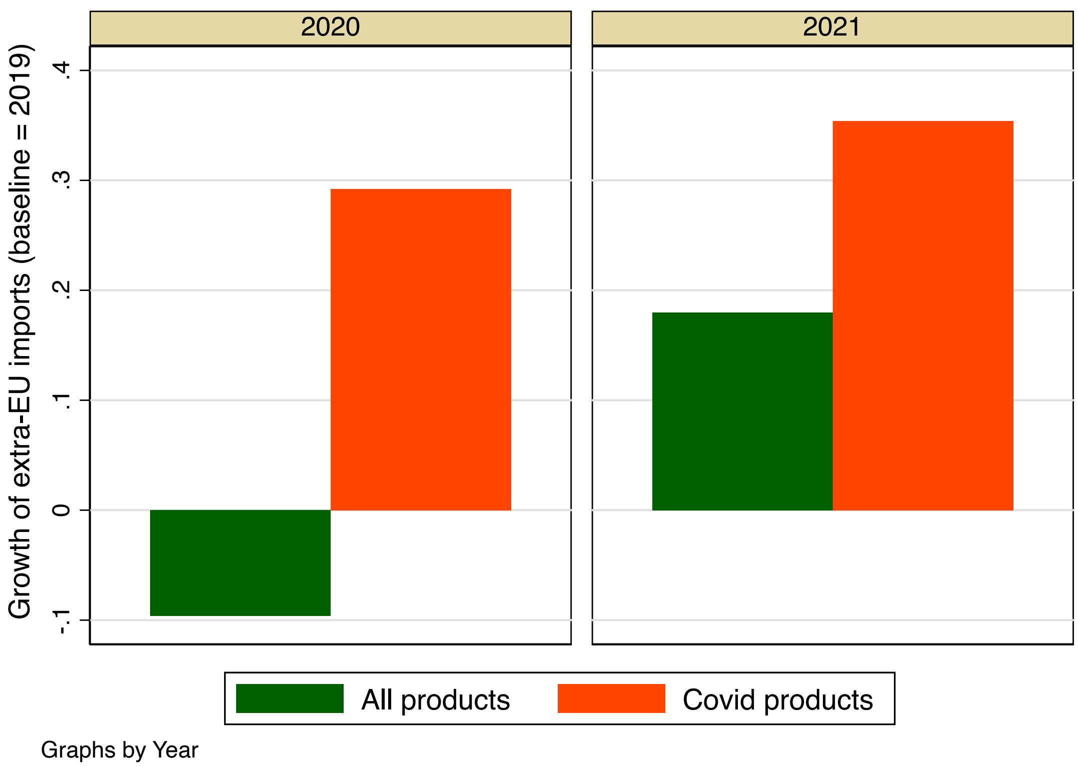
Notes: The Figure shows the evolution number of "strategic dependencies" and their contribution to aggregate imports, for active pharmaceutical when applying the criteria of European Commission (2021) and adding our absorption and stickiness criteria. Source: CEPII-BACI and Prodcom for 2019.

Figure B11: Geographical distribution of vulnerabilities on active pharmaceutical ingredients (APIs)



Notes: The figure shows the geographical distribution of trade vulnerabilities identified on APIs using the EC methodology (blue bars), the methodology augmented with the absorption criterion (red bars) and the methodology augmented with an absorption and a stickiness criteria (green bars). Source: CEPII-BACI and Prodcom for 2015 to 2019.

Figure B12: Growth of extra-EU imports between 2019 and 2020-2021: All products versus Covid-related products



Notes: The figure shows the growth of EU imports from non-EU countries in 2020 and 2021, using 2019 as reference. The figure compares aggregate imports and imports of products that were critical in fighting Covid-19, using the list of such products from the WTO.

C Additional Tables

C.1 A diagnosis of trade vulnerabilities

Table C1: List of strategic dependencies obtained using our five criteria methodology

Product	Exporter (market share)	HHI
Castor oil	India (98%)	0.96
Diphosphorus pentoxide	China (98%)	0.96
Heterocyclic compounds containing pyrimidine or piperazine ring, other derivatives of malonylurea	India (97%)	0.94
Alkaloids	United Kingdom (96%)	0.92
Quebracho extract	Argentina (96%)	0.92
Artificial flowers, foliage and fruit (of plastics)	China (95%)	0.90
Electro-thermic appliances (domestic purpose)	China (95%)	0.90
Bran, sharps and other residues	Argentina (93%)	0.87
Magnesium (raspings, turnings and granules)	China (91%)	0.83
Heterocyclic compounds containing pyrimidine or piperazine ring, malonylurea and its salts	China (90%)	0.82
Trichloroethylene	USA (90%)	0.82
Electric blankets	China (90%)	0.81
Vacuum flasks and other vacuum vessels	China (90%)	0.81
Nickel mattes	Russian Federation (87%)	0.76
Camping goods (of textile materials)	China (84%)	0.71
Phosphinates and phosphonates	China (83%)	0.70
Yarn of coir	India (82%)	0.70
Hair-dressing apparatus	China (81%)	0.67
Azelaic acid, sebacic acid and esters	China (81%)	0.67
Padlocks	China (81%)	0.66
Tents of synthetic fibres	China (80%)	0.65
Cases and containers (trunks, suit-cases, vanity-cases, etc.)	China (80%)	0.65
Borates: disodium tetraborate	Turkey (77%)	0.64
Magnets of metal	China (79%)	0.63
Fabrics, woven of jute	India (75%)	0.61
Silver nitrates	United Kingdom (73%)	0.60
Complex cyanides	China (75%)	0.58
Aromatic monocarboxylic acids and phenylacetic acid	China (73%)	0.56
Lighting or visual signalling equipment (bicycles use)	China (74%)	0.56
Cooking appliances and plate warmers	China (73%)	0.56
Iodine	Chile (73%)	0.56
Oxalic acid and esters	China (72%)	0.54
Yarn (not sewing thread) of synthetic staple fibres	Turkey (71%)	0.54
Saturated acyclic hydrocarbons	Russian Federation (70%)	0.53
Unwrought beryllium (powders)	USA (62%)	0.52
Disodium tetraborate (refined borax), anhydrous	USA (62%)	0.51
Hand or foot-operated air pumps	China (67%)	0.51
Wigs, false beards, eyebrows and eyelashes(of human hair)	China (70%)	0.50
Vulcanised erasers of non-cellular rubber	China (69%)	0.50
Tungstates (wolframates)	China (63%)	0.48
Interchangeable spanner sockets, with or without handles	Other Asia, nes (64%)	0.46
Vegetable waxes	Brazil (66%)	0.46
Rutoside (rutin)	China (63%)	0.45
Sleeping bags	China (65%)	0.45
Magnets other than of metal	China (64%)	0.43
Vulcanised gloves, mittens and mitts (other than surgical gloves)	Malaysia (63%)	0.42
Halogenated, sulphonated, nitrated or nitrosated derivatives	China (58%)	0.42
Bismuth	China (62%)	0.41
Ferrous products (by direct reduction of iron ore)	Russian Federation (60%)	0.40

Notes: The table lists the vulnerable products identified after applying our five criteria methodology. Source: CEPII-BACI for 2015 to 2019.

Table C2: List of strategic dependencies obtained using our five criteria methodology with a less restrictive stickiness criterion

Product	Exporter (market share)	HHI
Dichlorotrifluoroethane	China (100%)	1
Insulin and its salts	USA (99%)	0.98
Theophylline and aminophylline	Israel (98%)	0.96
Anti-knock preparations	United Kingdom (96%)	0.92
Artificial flowers, foliage and fruit other than plastics	China (95%)	0.90
Synthetic Yarn	Turkey (95%)	0.90
Umbrellas and sun umbrellas (excluding garden or similar umbrellas)	China (92%)	0.85
Unwrought thallium (powders)	Japan (91%)	0.83
Umbrellas and sun umbrellas (garden or similar umbrellas)	China (91%)	0.83
Weighing machines (personal and household scales)	China (90%)	0.81
Umbrellas and sun umbrellas (including walking stick umbrellas)	China (90%)	0.81
Maize (corn) oil and its fractions (crude)	USA (89%)	0.80
Christmas festivity articles	China (88%)	0.78
Alarm clocks, electrically operated	China (87%)	0.76
Wall clocks, electrically operated	China (86%)	0.74
Ferro-niobium	Brazil (85%)	0.74
Tennis, badminton and similar racquets	China (85%)	0.73
Beryllium	USA (84%)	0.71
Lamp : portable, electric, designed to function by their own source of energy	China (83%)	0.70
Earth-metals rare: scandium and yttrium	China (83%)	0.70
Amino-acids (other than those containing more than one kind of oxygen function)	Singapore (82%)	0.68
Musical boxes	China (082%)	0.68
Table, floor, wall, window, ceiling or roof fans, with a self-contained electric motor of an output not exceeding 125W	China (0.82%)	0.68
Lighters: pocket, cigarette, gas fuelled, refillable	China (81%)	0.67
Seats with metal frames (excluding medical)	China (80%)	0.65
Ties, bow ties and cravats of man-made fibres (not knitted or crocheted)	China (80%)	0.65
Travel sets for personal toilet, sewing, shoe or clothes cleaning	China (80%)	0.65
Synthetic Yarn	Turkey (80%)	0.65
Festive, carnival or other entertainment articles (other than Christmas articles)	China (77%)	0.61
Vegetable oils: palm kernel or babassu oil	Indonesia (74%)	0.61
Calcium	China (73%)	0.59
Hairpins, curling pins, curling grips, and hair curlers	China (75%)	0.58
Headgear of rubber or plastics	China (75%)	0.57
Toilet and kitchen linen of man-made fibres	China74%)	0.57
Cutlery (not plated with precious metal)	China (73%)	0.57
Yarn of jute	Bangladesh (72%)	0.56
Loudspeakers: multiple, mounted in the same enclosure	China (73%)	0.55
Shaving, hair, nail, eyelash and other toilet brushes for use on the person	China (72%)	0.5
Plastics: articles of apparel and clothing accessories (including gloves, mittens and mitts)	China (72%)	0.53
Cutlery: hair clippers and mincing knives	China (71%)	0.52
Optical devices, appliances and instrument (including liquid crystal devices)	China (69%)	0.50
Amino-naphthols and other amino-phenols (other than those containing more than one kind of oxygen function)	India (59%)	0.50
Arsenic	Japan (64%)	0.50
Saccharin and its salts	China (67%)	0.48
Handkerchiefs of cotton (not knitted or crocheted)	China (67%)	0.47
Cutlery (other than plated with precious metal)	China (65%)	0.47
Cases and containers with outer surface of sheeting of plastics or of textile materials	China (65%)	0.46
Bromine	Jordan (56%)	0.45
Anthranilic acid and its esters	China (59%)	0.45
Cases and containers of vulcanised fibre or of paperboard	China (66%)	0.45
Outboard motors for marine propulsion, spark-ignition reciprocating or rotary internal combustion piston engines	Japan (62%)	0.44
Aromatic monoamines and their derivatives	India (60%)	0.44
Synthetic Yarn: filament, monofilament of high tenacity yarn of polyesters	China (62%)	0.42
Halogenated derivatives of acyclic hydrocarbons containing two or more different halogens	USA (62%)	0.42
Radio broadcast receivers capable of operating without an external power source	China (61%)	0.40
Wattle extract	Brazil (46%)	0.40

Notes: The table lists the vulnerable products identified after applying our five criteria methodologyby retaining only the products after the first four criteria that have a stickiness higher than the median of the distribution in Martin et al. (2020).. Source: CEPII-BACI for 2015 to 2019.

C.2 A hierarchy of risks

Table C3: List of geopolitically risky strategic dependencies

Product	**Top X** (market share)	**HHI**
Mussels, prepared or preserved	Chile (99%)	0.98
Quebracho extract ✓ ✓	Argentina (96%)	0.92
Bran, sharps and other residues ✓ ✓	Argentina (93%)	0.87
Dark red, light red meranti and meranti bakau thicker than 6mm ✓	Malaysia (93%)	0.87
Pulp of fibrous cellulosic material	Philippines (85%)	0.74
Lithium carbonate	Chile (85%)	0.73
Molybdenum oxides and hydroxides ✓	Chile (80%)	0.65
Live, southern bluefin tunas (Thunnus maccoyii)	Tunisia (72%)	0.59
Iodine ✓ ✓	Chile (73%)	0.56
Coconut oil	Philippines (69%)	0.53
Fresh or chilled, southern bluefin tunas, excluding fillets	Tunisia (65%)	0.53
Copra	Argentina (70%)	0.52
Meat and edible meat offal of camels and other camelids	Chile (57%)	0.47
Chenopodium quinoa	Peru (54%)	0.44
Oil-cake and other solid residues ✓	Ukraine (61%)	0.43
Negligees, bathrobes, dressing gowns (women or girl) ✓	Tunisia (63%)	0.43
Vulcanised rubber, gloves, mittens and mitts other than surgical gloves ✓ ✓	Malaysia (63%)	0.42
Fireclay, whether or not calcined	Ukraine (55%)	0.41

Notes: The table lists the vulnerable products (identified with the EC methodology) imported from non-NATO countries with a GPR index above the median. The red and green checks represent the products identified as vulnerable after applying the absorption (red) and stickiness (green) criteria for this same set of countries. Source: CEPII-BACI for 2015 to 2019, Caldara and Iacoviello (2022) for the GPR index.

Table C4: List of highly concentrated strategic dependencies for API products

API	**Use**	**Top X** (market share)	**HHI**
florfenicol	Pathology of farm and aquatic animals	China (99%)	0.98
ethchlorvynol	Insomnia	Indonesia (0.99%)	0.98
daprodustat ✓ ✓	Anemia in people with chronic kidney failure	India (97%)	0.94
metharbital ✓ ✓	Epilepsy	India (97%)	0.94
fenproporex	Obesity treatment	Israel (95%)	0.90
alfentanil	Analgesia or as primary anesthetic agent during cardiac surgery	Switzerland (90%)	0.81
anileridine	Moderate to severe pain	Switzerland (90%)	0.81
bezitramide	Relieve pain	Switzerland (90%)	0.81
bromazepam	Short-term treatment of anxiety	Switzerland (90%)	0.81
difenoxin	Diarrhea	Switzerland (90%)	0.81
diphenoxylate	Diarrhea	Switzerland (90%)	0.81
dipipanone	Acute pain by mouth for adults	Switzerland (90%)	0.81
fentanyl	Severe pain (advanced cancer pain)	Switzerland (90%)	0.81
ketobemidone	Powerful opioid analgesic	Switzerland (90%)	0.81
methylphenidate	Children with attention deficit hyperactivity disorder	Switzerland (90%)	0.81
pentazocine	Moderate to severe pain	Switzerland (90%)	0.81
pethidine	Anesthesia in invasive surgery, postoperative analgesia, and general pain relief	Switzerland (90%)	0.81
phencyclidine	Intravenous anesthetic	Switzerland (90%)	0.81
phenoperidine	Opiod analgesic	Switzerland (90%)	0.81
piritramide	Postoperative pain	Switzerland (90%)	0.81
propiram	Analgesic	Switzerland (90%)	0.81
trimeperidine	Pain	Switzerland (90%)	0.81
arbaclofen ✓	Spasticity related to sclerosis and improve social function and behavior in patients with fragile X syndrome	Singapore (81%)	0.67
atagabalin ✓	Epilepsy and anxiety	Singapore (81%)	0.67
atrimustine ✓	Lower cholesterol and triglyceride levels in the blood	Singapore (81%)	0.67
dapabutan ✓	Antiseptic (gram-positive) bacteriostatic drug	Singapore (81%)	0.67
dicobalt edetate ✓	Antidote to cyanide poisoning	Singapore (81%)	0.67
eglumetad ✓	Anxiety and drug addiction	Singapore (81%)	0.67
etofenamate ✓	Muscle and joint paint	Singapore (81%)	0.67
imagabalin ✓	Generalized anxiety disorder	Singapore (81%)	0.67
lisadimate ✓	Sunscreens, to absorb UV radiation	Singapore (81%)	0.67
lumiracoxib ✓	Pain in osteoarthritis, rheumatoid arthritis, acute pain and primary dysmenorrhea	Singapore (81%)	0.67
meradimate ✓	Sunscreens, to absorb UV radiation	Singapore (81%)	0.67
mirogabalin ✓	Postherpetic neuralgia and painful diabetic peripheral neuropathy	Singapore (81%)	0.67
pregabalin ✓	Epilepsy and anxiety	Singapore (81%)	0.67
robenacoxib ✓	Postoperative inflammation and pain in dogs and cats	Singapore (81%)	0.67
sodium feredetate ✓	Iron deficiency anemia	Singapore (81%)	0.67
terofenamate ✓	Muscle and joint paint	Singapore (81%)	0.67
amfepramone ✓	Reduce feeling of hunger	Switzerland (78%)	0.66
methadone ✓	Detoxification and maintenance of patients who are dependent on opiates and treatment of patients with chronic, severe pain	Switzerland (78%)	0.66
normethadone ✓	Cough associated with inflamed mucosa	Switzerland (78%)	0.66
bimatoprost ✓	Glaucoma and ocular hypertension	USA (70%)	0.52
cobiprostone ✓	Lack of fluid secretion of the bowels	USA (70%)	0.52
ecraprost ✓	Reperfusion injury, peripheral arterial disease, diabetic neuropathies, lipid emulsion of ecraprost	USA (70%)	0.52
eganoprost ✓	Prostaglandines used in urology, obstetrics, and ophthalmology	USA (70%)	0.52
latanoprostene bunod ✓	Reduction of intraocular pressure in patients with open-angle glaucoma or ocular hypertension	USA (70%)	0.52
lubiprostone ✓	Stomach pain, bloating, and straining	USA (70%)	0.52
nobiprostolan ✓	Male pattern baldness and hypotrichosis	USA (70%)	0.52
posaraprost ✓	Prostaglandines used in urology, obstetrics, and ophthalmology	USA (70%)	0.52
rivenprost ✓	Lack of bone formation	USA (70%)	0.52
tafluprost ✓	Glaucoma and ocular hypertension	USA (70%)	0.52
treprostinil ✓	Certain kinds of pulmonary arterial hypertension	USA (70%)	0.52

Notes: The table lists the vulnerable APIs identified after applying the EC methodology and restricting to the one with an HHI above 0.5. The red and green checks represents the APIs identified as vulnerable after applying the absorption (red) and stickiness (green) criteria. Source: CEPII-BACI for 2015 to 2019.

Table C5: List of highly concentrated strategic dependencies for API products after applying our five criteria methodology, with a less restrictive stickiness creterion

API	**Use**	**Top X** (market share)	**HHI**
daprodustat	Anemia in people with chronic kidney failure	India (97%)	0.94
metharbital	Epilepsy	India (97%)	0.94
arbaclofen	Spasticity related to sclerosis and improve social function and behavior in patients with fragile X syndrome	Singapore (81%)	0.67
atagabalin	Epilepsy and anxiety	Singapore (81%)	0.67
atrimustine	Lower cholesterol and triglyceride levels in the blood	Singapore (81%)	0.67
dapabutan	Antiseptic (gram-positive) bacteriostatic drug	Singapore (81%)	0.67
dicobalt edetate	Antidote to cyanide poisoning	Singapore (81%)	0.67
eglumetad	Anxiety and drug addiction	Singapore (81%)	0.67
etofenamate	Muscle and joint paint	Singapore (81%)	0.67
imagabalin	Generalized anxiety disorder	Singapore (81%)	0.67
lisadimate	Sunscreens, to absorb UV radiation	Singapore (81%)	0.67
lumiracoxib	Pain in osteoarthritis, rheumatoid arthritis, acute pain and primary dysmenorrhea	Singapore (81%)	0.67
meradimate	Sunscreens, to absorb UV radiation	Singapore (81%)	0.67
mirogabalin	Postherpetic neuralgia and painful diabetic peripheral neuropathy	Singapore (81%)	0.67
pregabalin	Epilepsy and anxiety	Singapore (81%)	0.67
robenacoxib	Postoperative inflammation and pain in dogs and cats	Singapore (81%)	0.67
sodium feredetate	Iron deficiency anemia	Singapore (81%)	0.67
terofenamate	Muscle and joint paint	Singapore (81%)	0.67
fenetylline	Attention deficit hyperactivity disorder and narcolepsy	United Kingdom (39%)	0.29

Notes: The table lists the vulnerable products identified after applying our five criteria methodologyby retaining only the products after the first four criteria that have a stickiness higher than the median of the distribution in Martin et al. (2020). Source: CEPII-BACI for 2015 to 2019.