# Countries' unequal exposure to climate change impacts through international trade

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## Abstract

Countries can suffer supply chain disruptions and important economic losses when their trade partners are hit by natural disasters. As climate change intensifies, the frequency and intensity of climate-related extreme events are expected to increase, leading to an increase in this cross-border risk. However, the magnitude of this risk, and the relative exposure of different countries and different sectors is not clear. Here, we combine international trade data with climate risk indices to measure the exposure of countries' economies to foreign climate-related hazards, in the context of climate change. We find that this indirect exposure is highly heterogeneous between countries. While its geographical pattern generally differs from those of direct climate change impacts, several countries suffer a double exposure and are exposed to both risks, as a result of regional trade integration and geographic concentration of climate risks. Moreover, almost every country faces high exposure for at least one broad category of imports.

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## Introduction

Over the past few years, disruptions in global supply chains have emerged as a prominent policy concern. Even though not the only factor, meteorological events have contributed to this recent surge. For instance, the 2020-2023 global chip shortage has been partly attributed to the 2021 drought in Taiwan[1]. Similarly, the significant rise in global food prices since 2022 has been linked to the fact that the last few years ranked, globally, among the driest in the recent past[2]. As extreme events are predicted to intensify both in frequency and severity due to climate change, the climate driver of supply chain disruptions is expected to increase in the future[3]. This is why, alongside other channels such as finance networks, human migration, and geopolitics[4], trade has been recognized as a specific pathway for cross-border impacts of climate change: countries can suffer economic losses when their trade partners are hit by natural disasters. The risk has sometimes been estimated to possibly exceed the risk of local climate damages in some countries[5,6], but its quantitative assessments remain scarce, and it is generally not integrated into countries' climate change vulnerability assessments[7]. A better view of this risk could aid its integration into adaptation strategies, and facilitate cooperation between countries, which is essential for adapting to cross-border risks[8,9].

An emerging literature tries to measure and compare the exposure of countries to supply chain risks, through input-output[10,11] or customs data[12,13]. However, these studies, often conducted in the context of geopolitical trade competition or in the aftermath of the COVID-19 pandemic, define risk as 'being dependent on foreign countries' or 'importing products from a limited number of countries', with no consideration of climate change. Yet, as climate risk is heterogeneously distributed across the globe, depending on climate-riskier countries might be more of a concern in the future than depending on unspecified foreign countries.

Another body of literature explores the effect of climate change on supply chains but focuses on a limited number of economic sectors or climate-related hazards. Some studies analyze how climate change might affect international trade in a definite industry[14–18]. Other estimate the supply chain consequences of extreme events across all industries using economic models based on Multi-Regional Input-Output Tables (MRIOT), but focus on a limited number of climate-related hazards[6,19–22]. Hedlund et al. (2018) propose indicators to assess cross-border climate risks across multiple dimensions (e.g., transboundary water dependency, remittance flows, openness to asylum), with trade being one channel[23]. However, they measure exposure through trade solely by a country's openness to commerce, without distinguishing between trading partners of different risk levels.

Here, we aim at providing a first global view on countries' exposure to climate change impacts through international trade, considering all economic sectors and a wide range of climate change-related hazards. To do so, we combine the main publicly-available databases on global trade networks and country-level climate risks to systematically quantify national economies' exposure to potential supply-chain disruptions from climate change-related hazards.

We find a strong heterogeneity in cross-border climate risk. Notably, countries facing greater threats to their upstream supply chains tend to be countries also exposed to high climate risks on their own territory, as a result of both regional trade integration and geographic concentration of climate risks. However, all countries face significant exposure for at least one type of product. These conclusions appear robust across the diverse databases publicly available on climate risk and on trade.

# Results

## Methods summary

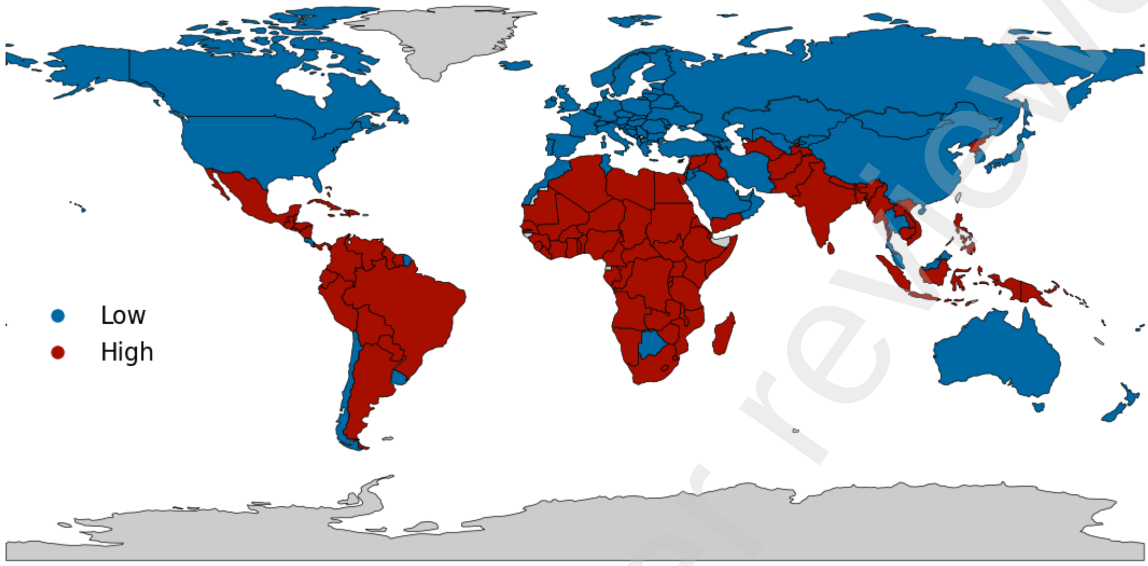
We use a framework originally proposed by Nakano (2017; 2021) to study the exposure of four countries' motor industry to foreign climate risk[17,24] , and we extend it to global, multi-sector and multi-hazard databases: we integrate multi-regional economic Input-Output data (MRIOT) with country-specific climate risk indices, to evaluate countries exposure to foreign climate risk through trade. Several multi-regional economic Input-Output data exist, and we rely here on 2 of the most widely used with a sufficient spatial and economic resolution: ICIO and EORA26[25,26] (see Experimental Procedures). Similarly, several climate risk indices exist, and we rely here on ND-GAIN and INFORM Climate Change, the only publicly available indices that are built explicitly on future climate change projections are used as country climate risk indices[27,28]. Even though all countries are concerned with climate change, the degree of climate risk, as measured by hazards, exposure and vulnerability is spatially heterogeneous. We use the climate risk indices to classify countries into two levels of local climate risk, low and high (Experimental Procedures, Fig. 1). Trade-related cross-border climate risk is multifaceted: companies are exposed because they import intermediate consumption from high risk countries but also because they export goods and services to foreign companies and consumers. Households, for their part, face risks on imported final consumption. For a given country, we define four measures of exposure: cross-border climate exposure on imports of intermediate consumption, on imports of final consumption, on exports to foreign consumers, and on exports to foreign companies. They are defined as trade dependence on the climate-riskiest countries, i.e. the share of imported (resp. exported) intermediate consumption (resp. final consumption) coming from (resp. going to) high climate risk countries. By construction, exposure is a product of dependence on foreign countries (i.e. how reliant a country's economy is on imports or exports) and share of trade with high climate risk countries (i.e. the percentage of imports or exports from or to countries with a high climate risk) (see Experimental Procedures and Supplementary Material A).

## Cross-border exposure is heterogeneous across countries

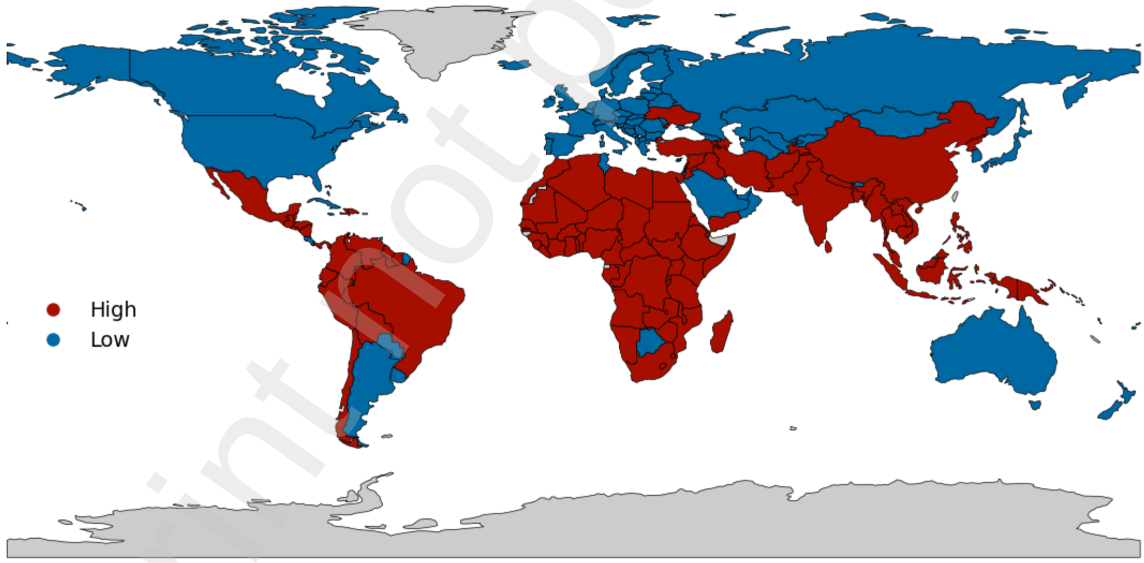
The value of cross-border exposure indicators relies on the choice of a specific risk index and input-output table (see Supplementary Material B). For instance, the level of exposure hinges on whether China is deemed a high climate risk country or not. Nevertheless, several qualitative messages remain valid across all configurations of climate risk index and input-output tables. First, cross-border climate exposure varies significantly between countries. If we use INFORM Climate Change for climate risk and EORA26 for trade data, for instance, we find that the median exposure for intermediate consumption is 5.4%, while it is more than twice higher (13.1%) for the top 10% of countries (figure 2, see also Supplementary Material B Fig. 1 for results with other datasets). This discrepancy is due to both large variations in the dependence on foreign countries (while median is 22%, 90th percentile is 34%) and in the share of high risk suppliers (median 32% and 90th percentile 48%) (see Supplementary Material B Fig. 2 and Fig. 3 for all results). Dependence on foreign countries and share of high risk suppliers are generally both lower than 40%, because production is predominantly meant for intermediate or final consumption at the national level, and low risk countries account for a high share of global trade (53% of trade in intermediate products occurs between low risk countries and 41% between a low and high risk country).

**Figure 1 - Climate Risk by Country according to ND-GAIN and INFORM Climate Change**

Panel (a) ND-GAIN Index



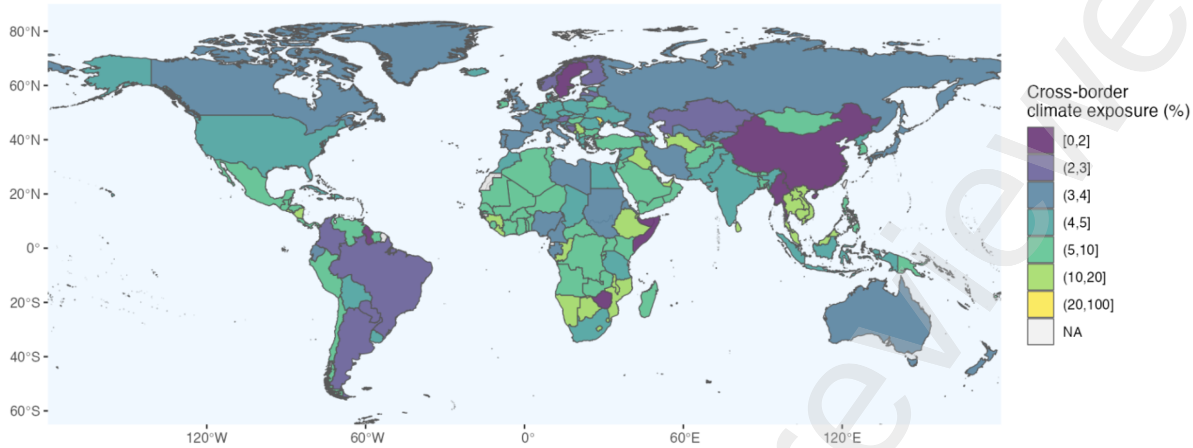

Panel (b) INFORM Climate Change Index



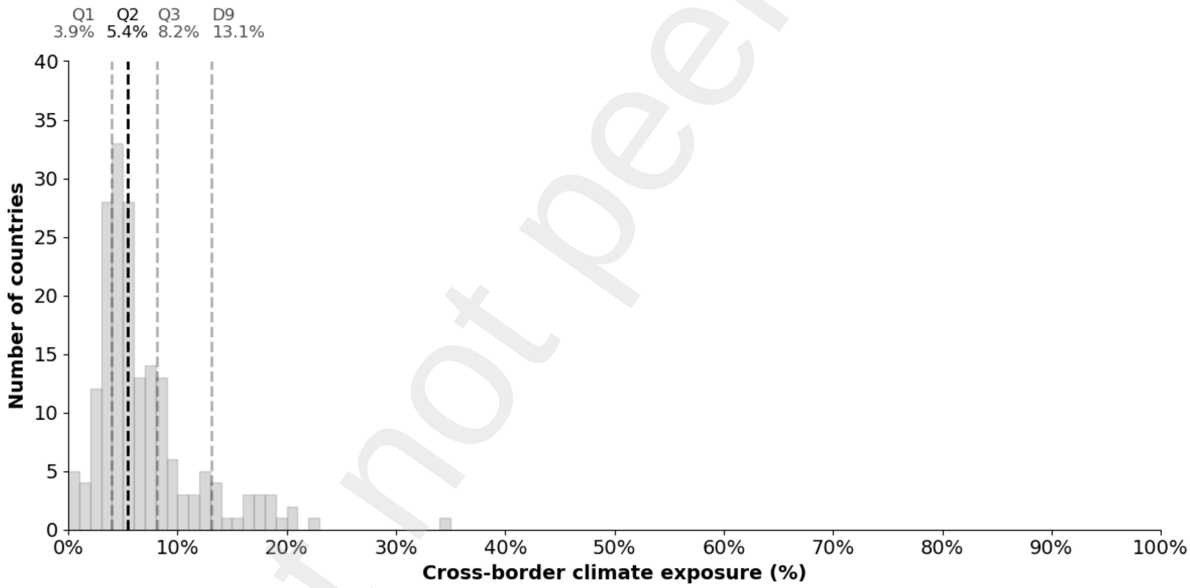

*Lecture: INFORM Climate Change risk index is available for several warming scenarios and reference year. The pessimistic scenario (RCP8.5) in the year 2050 has been chosen here.*

**Figure 2 – Distribution of cross-border climate exposure across countries (data used: INFORM Climate Change for climate risk, EORA26 for global trade data)**

Panel (a) Map of cross border climate exposure for imports of intermediate consumption




Panel (b) Distribution of cross border climate exposure for imports of intermediate consumption




*Lecture: On Panel b, first (Q1) and third (Q3) quartile, median (Q2) and 9th decile (D9) of the distribution are indicated. See Supplementary Material B and C for robustness tests with other datasets.*

## Developed countries are among the least exposed for imports

Identification of countries least and most exposed differ when considering exposure on imports or exports. For imports of intermediates, developed countries are among the least exposed to climate cross-border risk: with a median exposure of 4.2%, 75% of developed countries exhibit lower exposure than the global median, and 88% show lower exposure than the median for non-developed countries (Supplementary Material B Fig. 4a). Among developed countries, all in North America and 93% in Western Europe fall below the global median. However, the underlying reasons vary among countries. Figure 3a categorizes countries based on two criteria: whether their dependence on foreign countries exceeds the global median and whether their suppliers present higher risks than the global median. Some developed nations exhibit low cross-border exposure due to their low dependence on foreign countries, despite having a high proportion of high-risk suppliers (e.g., the US). In contrast, others have a high dependence on foreign countries but a low proportion of high-risk suppliers (e.g., most European countries).

The disparity in exposure on imports between developed and other countries can be explained by the fact that, in general, a large fraction of a country's trade is with its immediate neighbours[29], and that climate risks are geographically concentrated[30]. In fact, the relationship is significant: the riskier a country is, the higher the proportion of its suppliers is exposed to climate risk (Figure 3c). While the extent of foreign dependence for a country depends on factors such as the size of an economy or its position in the international division of labor[11], the share of high climate risk trade partners is correlated to whether or not a country is itself at high climate risk. Developed countries, which are among the least climate-risky according to risk indices (see Supplementary Material F), also have a lower share of high climate risk suppliers (20%), compared with developing/least developed countries (35%) (Supplementary Material B Fig. 4c).

## High cross-border risk countries tend to be at high local risk

The countries most exposed to cross-border risk are situated in the upper-right corner of Figure 3a and tend to be among developing and least developed nations. Furthermore, consistent with the observation that the riskier a country is, the higher the proportion of its suppliers exposed to climate risk, the majority (68%) of countries in this quadrant are also among those most directly affected by climate change impacts. This figure is even higher if we take into account countries population size (Figure 3b): 94.2% of people living in high cross border risk countries live in high direct risk countries (see Supplementary Material C Fig 2 for more results). Conversely, populations at low risk are predominantly situated in areas of low to moderate exposure.

Previous results were given for imports of intermediate consumption. The classification of countries with low and high exposure appears similar for imports of final consumption as well (see Supplementary Material C).

## Exposure through exports differs from exposure through imports

On the contrary, assessing cross-border climate exposure for exports rather than imports yields different results. While the order of magnitude of the exposure is similar to that observed for imports, the ranking of countries changes: developed nations are no longer positioned at the lower end of the exposure distribution (Supplementary Material C) and high-cross border risk countries are not mainly high risk countries. This occurs mostly because production in developed countries is typically more export-oriented than in developing/least-developed countries: although the proportion of imported intermediate consumption is comparable between these two groups (23.9% and 21.4%), developed countries have a higher share of exported gross output, at 26.4% compared to 16.6% for developing/least developed. Also, while developed countries consistently both import from and export to fewer high risk partners than their developing and least-developed counterparts (19.5% vs 35.4% for imports and 25.5% vs 31.8% for exports), the difference is smaller for exports. Overall, the higher degree of economic openness offsets the lower proportion of trade with risky partners (for all results, see Supplementary Material C Table 1).

However, despite this asymmetry between imports and exports, since countries with high cross-border risk for imports are mainly those with high local risk, countries that accumulate high cross-border risk for both imports and exports are predominantly high local risk countries.

It should be highlighted that, from a policy perspective, exposure via exports differs from exposure via imports in several key aspects. First, it primarily impacts companies: consumers may indirectly experience income losses but this effect is out of our framework. Second, when an extreme event strikes a location, it disrupts local production and poses a clear risk for countries that import from that area. However, the impact on firms exporting to the affected area is ambiguous: Exports may decrease due to a reduction in economic activity, but they could also increase to compensate for the loss in local production, potentially benefiting trading partners.

## Low aggregate exposure might conceal high exposure at product level

The low level of aggregate exposure can nonetheless conceal high exposure for certain categories of goods. The median exposure to imports for intermediate consumption is 5.4% at the country level across all nations, while the exposure for certain products is significantly higher. 185 out of 187 countries have an exposure above 10% for at least one imported product, and the median exposure across countries for the most exposed product in each country is 32%. The same applies to exports of intermediate consumption: 186 out of 187 countries have an exposure above 10% for at least one exported product, and the median exposure across countries for the most exposed product in each country is 27%.

More specifically, even developed countries, which are among the least exposed through upstream supply chains, are highly exposed through the import of several items. Using ICIO, the MRIOT with finer sectoral resolution, we find that the most exposed categories of goods are mostly manufacturing products or raw materials, such as textiles (24%), mining and quarrying (20%) or electronics (19%), to be compared with an aggregate exposure of 3.1% with ICIO (Figure 4a). On the exports side, products such as basic metals (11%), chemical products (7.5%) or rubber and plastics products (6.9%) have an exposure level higher than aggregate level (3.3%) (Figure 4b). Products with high exposure differ between imports and exports (see Supplementary Material D for results with all databases).

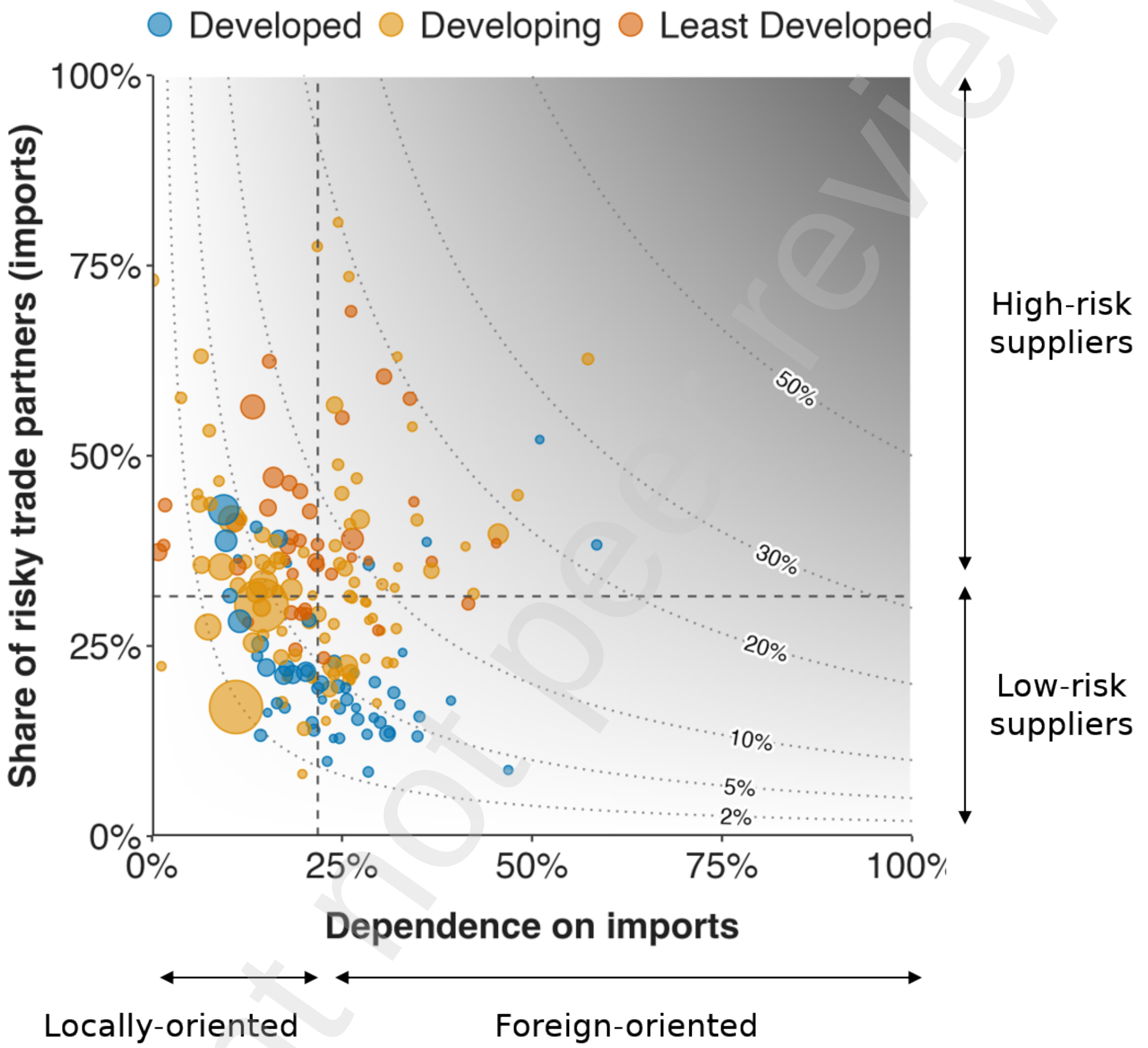
Exposure to imported products can be particularly problematic if it involves items with concentrated sources: when the majority of these goods come from a limited number of countries, it becomes more difficult for firms to find alternative suppliers in case of extreme events in one of those regions. It appears that, in developed countries, the most exposed imported products tend to be those with a particularly concentrated supply, when compared to all available products (Supplementary Material D Fig.3).

Finally, heterogeneity in exposure by product leads to a situation where economic sectors are not all affected the same way, as each sector tend to use imported inputs of different types. In developed countries, the impact on economic sectors is uneven: The production of textiles (9.4%) and electronic and electrical equipment (8% and 7.9%, respectively) face an exposure that is double that of the entire economy, as they rely, more than other economic sectors, on imports from countries with high climate risks. However, the difference between aggregate exposure and the highest sector exposure is smaller than the difference between aggregate exposure and the highest exposure by product (Supplementary Material D Fig.4).

It should be noted that all results presented here depend on the quantitative threshold that distinguishes between low and high climate risk. However, our qualitative conclusions remain robust when performing a sensitivity analysis on this parameter (see Experimental Procedures and Supplementary Material E).

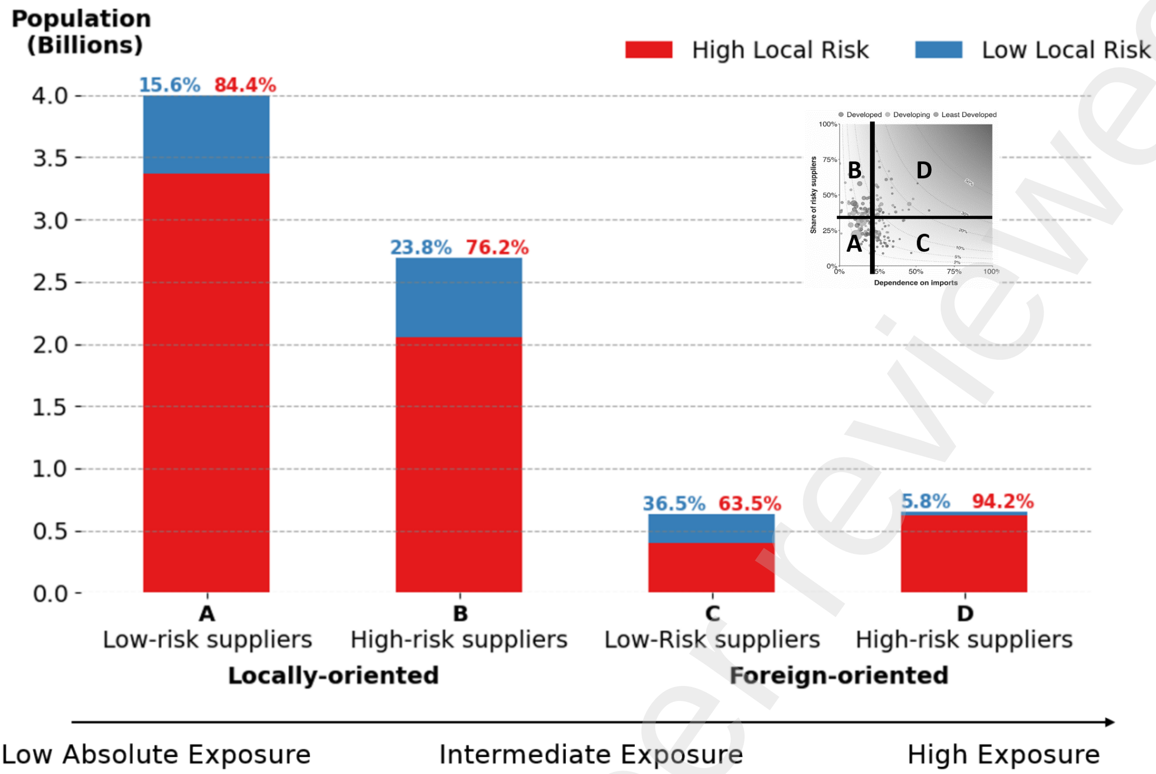
**Figure 3 – Countries most and least exposed to cross-border trade impacts (data used: INFORM Climate Change for climate risk, EORA26 for global trade data)**

(a) Distribution of cross-border climate exposure for intermediate consumption across countries. Cross-border climate exposure (greyscale background color) can be due to more economic dependence on import from foreign countries (x-axis) or higher share of high risk suppliers (y-axis).



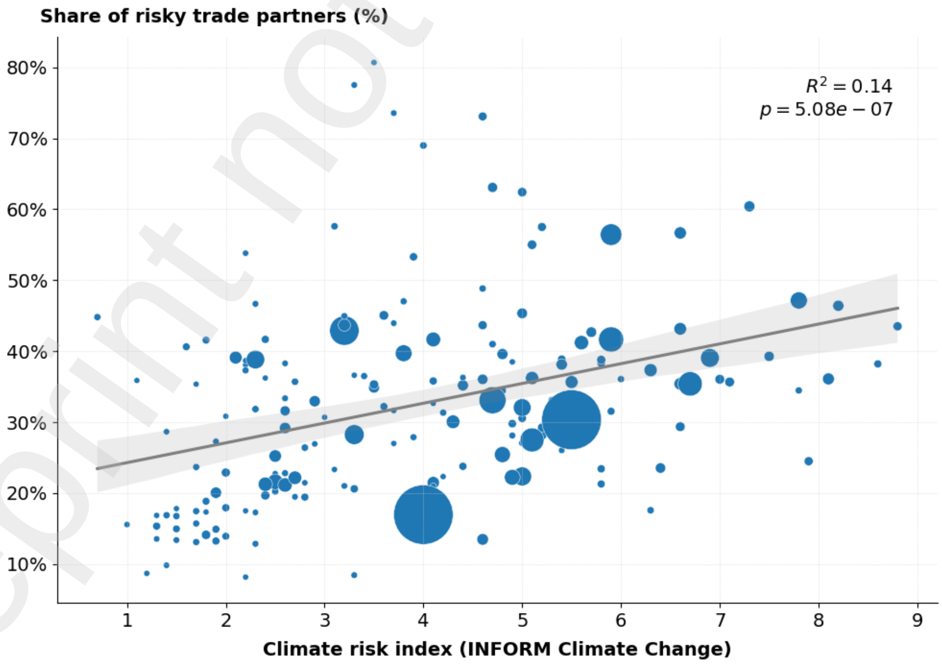

*Lecture: Each country is represented by a dot, whose magnitude is proportional to the country's population, and colour indicates its development level. Dotted horizontal and vertical lines indicate median dependence on foreign countries (imports) across countries and median share of high risk suppliers. Dotted hyperbolas indicate constant cross-border climate exposure. Each quarter of the figure corresponds to a column of Panel (b).*

(b) Share of Population Living in High or Low Local Risk Country in Each Quadrant of Panel (a)




*Lecture: Each column shows how much of the population of a quarter (A, B, C and D) of Panel (a) lives in a high or low climate risk country. Population is shown instead of the number of countries pertaining to each category to avoid bias induced by low-risk small countries.*

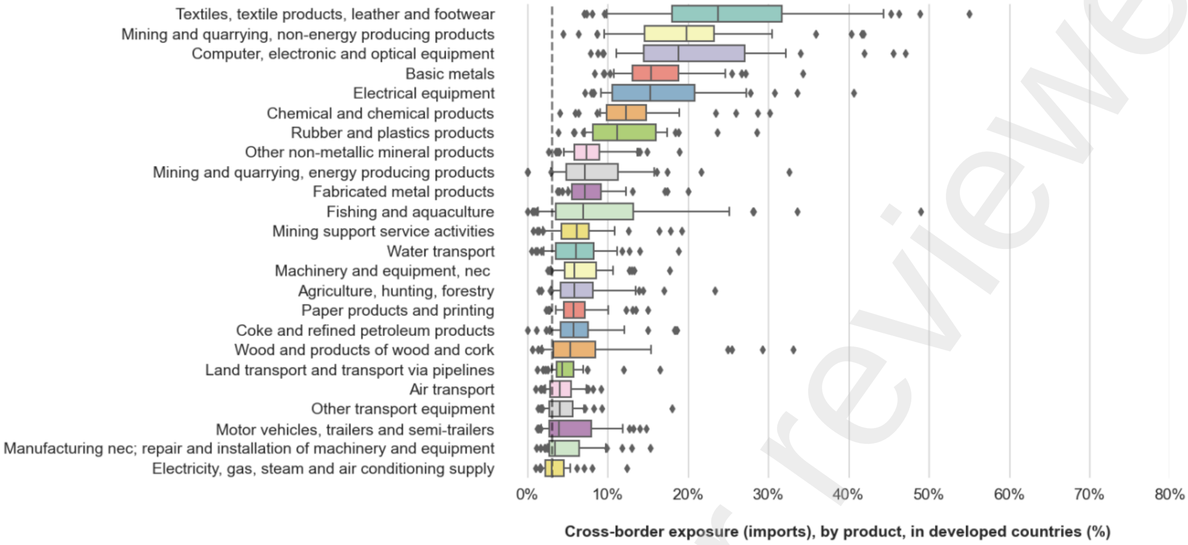
(c) Relationship between Local Climate Risk and Share of High Risk Trade Partners.



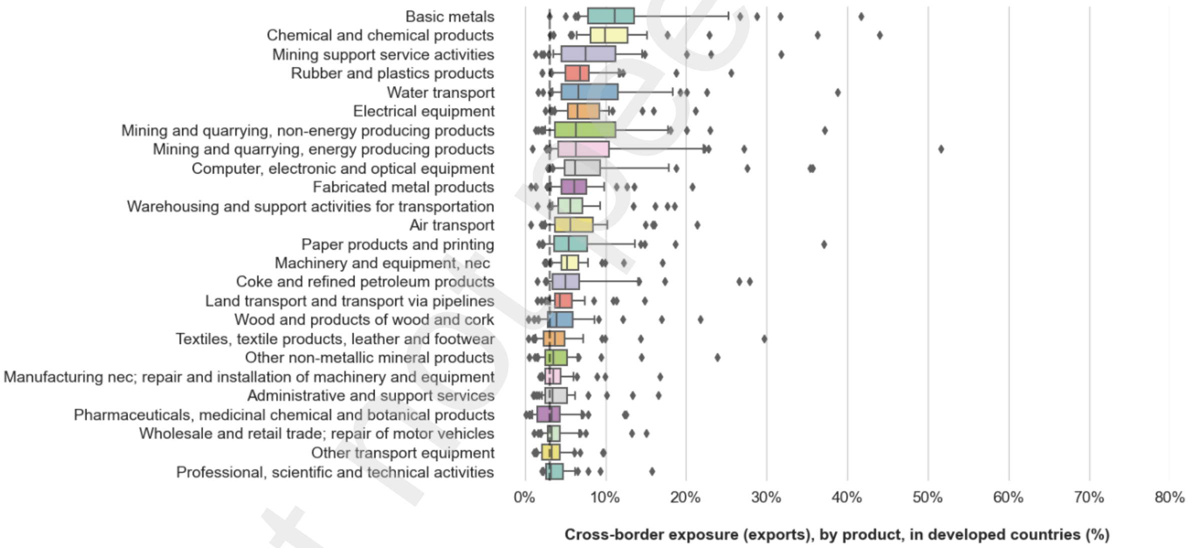

*Lecture: Each point represents a country, and a point size is proportional to the country's population. A regression line is plotted along with R2 and p-value indicating that local climate risk is significantly related to the share of high risk suppliers.*

**Figure 4 – Exposure by product, among developed countries, for the most exposed sectors (26 sectors out of 45) (INFORM Climate Change, ICIO)**

Panel (a) Imports of intermediate production




Panel (b) Exports of intermediate production




*Lecture: For each selected product of the ICIO tables, a box plot represents the distribution of cross-border climate exposure on imports (Panel a) and exports (Panel b) of intermediate consumption among developed countries. The vertical dotted line represents sector-aggregated median exposure for developed countries (3.1% for imports and 3.3% for exports). Boxplots indicate median, lower and upper quartiles while whiskers extend 1st and 9th deciles. Only sectors where median exposure is above aggregate exposure are selected: 26 (imports) and 24 (exports) out of 45 (see Supplementary Material D Fig.2a, for all sectors).*

## Discussion and conclusion

An important limit of our approach is the fact that it compares current trade networks to future climate risks. Trade patterns are expected to evolve in the future due to socioeconomic factors. For instance, a large share of future economic growth is expected in Africa and Asia, regions that are currently considered to be at high climate risk[31]. However, the effect on cross-border climate exposure is uncertain. While economic growth may increase trade with these areas, it could also reduce their vulnerability, and lower their climate risk index.

Available climate risk indices and trade data also limit our investigation. First, as climate risk is given by a country index, sub-national risk heterogeneity is not represented (i.e. risk in one part of a country *vs.* in another). However, as climate risk is often homogeneous across world regions, spanning on multiple countries[32], and as human activity is often located in the more vulnerable areas at the subnational level[33], the impact on our result may either be moderate or lead to an underestimation. Second, the same risk level is given for all types of economic activities, while some industries are more vulnerable than others to climatic conditions (for instance, agriculture *vs.* manufacturing). Nevertheless, even though sectors are not equally vulnerable to climate change, extreme events have the potential to disrupt any economic sector (e.g. manufacturing or services might be impacted by heatwaves, droughts impact tourism, energy production and not only agriculture)[34]. In the future, development of climate risk indices by sectors could help refine our assessment.

A thorough evaluation of the economic costs associated with the cross-border risk should take into account market mechanisms (e.g. substitution between suppliers or buyers) or network effects (e.g. amplify direct costs because of low substitution or low product homogeneity[35,36]). Such features cannot be assessed with the data used here, but models of economic cost propagation through trade networks, a field in rapid development, could be employed to this end, by progressively incorporating a broader range of direct impacts[21,22]. Policies designed to foster resilience to cross-border trade climate impacts could also be informed by integrating customs data and climatic risk indices, for finer targeting at product level, and therefore better consideration of non-substitutability between suppliers[12].

To sum up, exposure to climate change through global supply chains varies greatly between countries. The countries most exposed through upstream supply chains are already at high direct risk, as a result of both regional trade integration and geographic concentration of climate risks. Conversely, developed countries, which are relatively less at risk from climate change, exhibit lower exposure to cross-boundary risks on their imports. However, disaggregating by economic sectors shows that even these lower exposed countries face strong sector exposure on a wide range of manufacturing goods.

This shows that, from a developed countries perspective, financing climate adaptation in the Global South could be justified from a national resilience perspective. Besides, several developing or least developed countries appear to be doubly disadvantaged: both by direct climate impacts and trade cross-boundary risks. These results both confirm and refine the concerns of "double exposure" of the poorest countries, already highlighted by Hedlund et al. 2018[23]. Diversifying future trade could be a solution for them, even though trading with more distant partners might be costlier. There is an academic debate about whether international trade could enhance resilience or lead to higher exposure to climate change impacts[19,37]: our results highlight that the choice of trade partners plays a key role in this issue.

# Experimental Procedures

## Resource availability

*Lead contact*

Further information and code support should be directed to the corresponding author, Adrien Delahais (adrien.delahais@enpc.fr).

*Data and code availability*

Scripts to reproduce results and figures can be found at: https://github.com/ADelahais/cross-border_risk_exposure.

## Trade networks

Trade networks are described through OECD Inter-Country Input-Output (ICIO) (2018 version)[25] and EORA26 (2016 version)[26], two sets of Multi-Regional Input Output Tables (MRIOT). Designed to study international trade, ICIO has a detailed description of economic sectors (45) and is centred around 66 countries that account for more than 90% of annual trade. It has been used in projects which aim at assessing and comparing countries' dependence on foreign clients and suppliers[10,11]. EORA26 on the other side is coarser in terms of sector disaggregation (26 sectors) but takes into account more than 180 countries, which allows to describe trade among high climate risk countries in Africa or Asia. Other often used MRIOTs, such as WIOD[38] or EXIOBASE[39], do not cover as many countries (respectively 43 and 44 countries).

## Climate risk indices

Several climate risk indices have been developed by public institutions to help decision makers pinpoint countries most at risk from actual and future climate change[40–42]. Here, we use ND-GAIN and INFORM Climate Change, the only publicly available indices that are built explicitly on future climate change projections[27,28]. Each country is given a climate risk score that accounts for hazard, exposure and vulnerability. While ND-GAIN represents a wide range of climate impacts (e.g. food production, water availability, health, infrastructure), INFORM Climate Change focuses on future population exposure to climate change related hazards (flood, drought, epidemics) (Supplementary Material A for a detailed presentation of climate risk indices). We categorize countries into two groups: low and high future local climate risk, through a threshold score. INFORM Climate Change already distinguishes five risk categories (very low, low, medium, high, and very high), based on a clustering method. We set the threshold at 3.5/10, that is between original low and medium risk categories. No risk classification is already available for ND-GAIN: 50/100 is chosen so that the list of high risk countries is generally consistent between both indices. These lists align well with both multidimensional risk analysis[30,32] and the literature on climate change impact on GDP[43,44] (Supplementary Material F). See Extended Data Fig.1 for a visual representation of the division between countries with low and high local climate risk. Our results are robust to a sensitivity analysis on these thresholds (Supplementary Material E). The categorization of countries into "developed", "developing" and "least developed" is sourced from the statistical portal of the United Nations Conference on Trade and Development[45].

## Measuring cross-border climate exposure

Global trade networks data are combined with country indices characterizing future climate risk. For a given country, both firms and consumers are exposed to climate impacts through international trade. Companies are linked to high climate risk countries through import of intermediate consumption and export of their own production. Households face risks on imported final consumption. We define four measures of exposure: cross-border climate exposure on imports of intermediate or final consumption, on exports to foreign consumers or foreign companies. They are defined as trade dependence on the climate-riskiest countries, i.e. the share of imported (resp. exported) intermediate consumption (resp. final consumption) coming from (resp. going to) high climate risk countries. This can be determined using the Leontief matrix, which accounts for both direct imports (resp. exports) from (resp. to) high risk countries and indirect exposure, as high risk countries are present upward along the supply chain[46] (see Supplementary Material A for explicit formulas and discussion). By definition, exposure is a product of dependence on foreign countries and share of trade with high climate risk countries (Supplementary Material A).

## Robustness analysis

The indicators were separately computed 4 times with each database choice (ND-GAIN/ICIO, ND-GAIN/EORA26, INFORM/ICIO, INFORM/EORA26), and for each of the 4 types of exposure (imports of intermediate and final consumption and exports for intermediate and final exposure, see Supplementary Material C). Robustness checks have also been done on risk thresholds (Supplementary Material E). In the main text, when presenting indicators on country aggregate exposure, we mostly refer to results obtained with EORA26 to cover as many countries as possible. We mostly refer to results obtained with ICIO to quantify exposure by product, since its higher number of sectors offers a finer description of international trade.

## Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT 4o to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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## Author contributions

Conceptualization, A.D. and V.V.; methodology, A.D. and V.V.; data curation, A.D.; writing – original draft, A.D. and V.V.; writing – review & editing, A.D. and V.V.; supervision, V.V.

## Declaration of interest

The authors declare no competing interests.

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