GEOPOLITICAL RISK INDEX

Geoeconomic Dependency

TABLE OF CONTENT

GEOPOLITICAL RISK INDEX: GEOECONOMIC DEPENDENCY

DATA GROUP 2 – MAY 2024

Francesco Antonio Bargellini, n. 3110609

Tommaso Camisasca, n. 3108108

Antonio Evangelista, n. 3089577

Leonardo Garbo, n. 3230695

Sara Trapani, n. 3096248

ABSTRACT

The increase in interest towards Geopolitics has become a key trend in the recent years. The relevance of this phenomenon has forced students, scholars and practitioners to acquire new knowledge and skills to face an unstable and ever-changing global scenario. Since 2022, the Geopolitical Risk Index Project, created by Professor Andrea Colli, Dr. Gian Maria Mallarino and students of the Geopolitics for Business course at Bocconi University, has advanced the research in this field by establishing an innovative tool to measure the country-level risk faced by actors, such as multinational corporations and investors. This report describes the actions undertaken to improve the existing work of previous students regarding the Geoeconomic Dependency Sub-Index. The main areas of transformation include the Excel database structure, data sources and method of indexation. Having in mind the key goals of expanding the index in both historical depth and geographical reach, we were able to calculate the index for the year 2021 as well as for 2022, filling a gap with extreme relevance due to the importance of providing recent data. In addition, we have expanded the availability of the Geoeconomic Dependency Sub-Index in the time range 2007-2015, having reached the maximum size allowed by the sources for all the Sub-Sub-Indexes. Furthermore, the use of well-established databases (e.g., Word Bank), following the original strategy of the creators of the Geoeconomic Dependency Sub-Index, has allowed the calculation of the Sub-Index for 252 countries and geographical entities.

INTRODUCTION

The year 2024 marks the 3rd edition of the Geopolitical Risk Index (GRI) Project developed in the context of the Geopolitics for Business course at Bocconi University. In 2022, Group 6 was tasked with the creation of one of the six sub-indexes, specifically the Geoeconomic Dependency Sub-Index, included in the Geopolitical Risk Index. The goal was to capture the risk associated with the economic interconnections among countries, represented for example by the reliance on high levels of import or export, which could be used as instruments of power by competing nations. The Sub-Index is expressed in a 0 to 10 scale (with 0 being "no risk" and 10 "highest risk") and was originally composed by 7 equally weighted sub-sub-indexes: energy, raw materials, agriculture, global value chain (GVC), technology, finance and foreign aid. The assignment for the Data Group in the 2023 Edition was to improve the previously created Index by increasing the number of years available as well as the number of countries in the GRI. In relation to the Geoeconomic Dependency Sub-Index, three main modifications have been made: removal of the GVC sub-sub-index, new approach to unavailable data, inclusion of the years 2020 and an approximation for 2021.

Following the objectives established in 2023, the primary task assigned by the Project Leaders Prof. Colli and Dr. Mallarino for the 2024 edition was to continue the expansion of the GRI both in historical depth and geographical reach. In addition, we have developed our work keeping in consideration a secondary objective, i.e. the enhancement of the transparency and reliability of the database, both in sources and methodology, in order to improve its significance and to facilitate the future upgrades of the Sub-Index. During the analysis and development of the project, we ensured to justify our actions by providing a technical, economic or geopolitical rationales.

The subsequent sections are structured as follows: Chapter 1 focuses on the preliminary analysis of the existing sub-index and the required corrections, Chapter 2 delves into the specific sub-sub-indexes and their individual improvement, while Chapter 3 describes the general modifications implemented at sub-index level. Chapter 4 and Chapter 5 summarize the limitations and the conclusions of the project.

1 RECTIFICATION OF PREVIOUS WORK

1.1 Global Value Chain (GVC) Exclusion

The GVC Sub-sub-index represented one of the limiting factors in the first edition of the Geoeconomic Dependency Sub-Index, due to the low number of countries and the narrow time window (2016-2018) available compared to the other sub-sub-indexes. For this reasons, the 2023 Data Group decided to remove it from the calculation of the Final Sub-Index, as evident from the 2023 Excel Database, where the "Final Grades" sheet does not include GVC and the "GVC" sheet is not updated past 2018. Furthermore, the Foreign Aid Sub-sub-index has been updated to 2020 (the most recent year with reported data for the 2023 edition) and included in the calculations.

However, both the 2023 Presentation and 2023 Report state that the removed sub-sub-index is Foreign Aid, and not GVC. Based on the evidence from the Excel file, it is possible that the removed sub-sub-index has been mistakenly identified in the two written documents, compared to the actual modification in the Database.

In the 2024 version of the Database, we have kept the "GVC" sheet, cancelling the values and replacing them with a brief indication of the removal process, including the misidentification of the sub-sub-index with Foreign Aid.

1.2 Approach to missing data

One of the modifications introduced with the 2023 version of the Geoeconomic Dependency Sub-Index was an innovative approach to the presence of non-available values in the raw data.

This problem is strictly connected with the nature and the source of the data chosen to calculate the Geoeconomic Dependency Sub-Index. The World Bank Databases - both the one directly available from the WB website and the one from the WITS software, which is managed and used by the World Bank as well - are used for five out of six sub-sub-indexes, leaving out only Technology. On one hand, this choice

allows to cover a significant number of years in the past (up to 1962 for some indicators), an option that we have fully exploited from this year by including this extensive historical depth for all the eligible sub-sub-indexes (see the individual sections in Chapter 2 for further details). Furthermore, the general sample of political and geographical (e.g., "East Asia & Pacific") entities included in the Database is quite comprehensive, totalling 266, with 217 countries and 49 other entities. On the other hand, the Database presents a significant limitation, clearly recognized in the original paper: for each country not all years are available, and for each indicator not all countries are available. This is connected with the fact that the raw data from this sources is not composed by scores or ranks assigned by researchers, but from actual values (e.g., % of imports), that for several reasons may be not available for a particular year/country in the non-index specific general sample of nations.

This feature creates some distinctive "blank spots" in the data. As consequence, working with this Databases requires accepting a trade-off between the year-to-year/country-to-country comparability of the Final Grades and the availability of an extensive, both geographically and historically, final sample.

The approach chose by the first group tackling the Geoeconomic Dependency Sub-Index in 2022 was to simply leave the "blank spots" as missing values in their final calculations for the Sub-index score. However, given the fact the formula was a simple average summing the country/year values for each sub-sub-index and then dividing by 7 (as mentioned in the introduction, the first edition still included GVC), the blank spot was implicitly assigning a value of 0 for the missing country/year observation. As a consequence the final grades were substantially underestimated, especially since the GVC Sub-sub-index displayed very few observations.

In 2023 the issue was addressed with a new approach (Adamsson et al., 2023):

i.   Each "blank spot" was assigned a "n.a." (non-available) value;

ii. All available country/year observations for each sub-sub-index were summed;

iii. The total was then divided by the number of available sub-sub-indexes.

This method effectively overcame the underestimation problem (except for the issue of some sub-sub-indexes with structurally low values due to the indexation method,

which will be addressed in chapter 3.2), with one notable deviation: the Finance Sub-sub-index.

Differently from all the other sub-sub-indexes, the Finance Sub-sub-index presented no "n.a." values or "blank spots". On the other hand, it showed a significantly high number of "0" values. In particular, some countries displayed all "0" observations for all the years under analysis (2016-2020). Moreover, most of these same countries reported "n.a." values for all the other sub-sub-indexes using the World Bank as source. It is possible to conclude that for a sample of the countries affected by this phenomenon, there was most likely no actual available data for all the sub-sub-indexes, including Finance, for each of the years in the database. This deduction is further reinforced by the fact that the affected countries are very small nations or territories under control of other bigger entities (e.g., British Virgin Islands, Channel Island, Isle of Man, Puerto Rico). In conclusion, a probable calculation mistake in the Finance Sub-sub-index led to the generation of "0" values instead of "n.a." values.

The ultimate consequence of this flaw in the data is the fact that the 2023 Geoeconomic Dependency Sub-index final score contained no "n.a." values or "blank spots", which would have appeared as a consequence of the new approach assigning "n.a." values at sub-sub-index level.

The reason why we have highlighted this fact is the focus we have put on increasing the reliability and accuracy of the Geoeconomic Dependency Sub-index, parallel to the key objective of size extension. This is a relevant concern, given the fact the GRI Project represents a combined effort by a large number of students analysing several Sub-indexes, and all the choices bear Index-wide consequences.

As detailed further in Chapter 2 of this Report, in the 2024 edition of the Geoeconomic Dependency Sub-index we have addressed several improvement points in the Database, which have led us to essentially re-develop the calculations for the sub-sub-indexes. Consequently, as reasonably foreseeable by the previously explained nature of the raw data and the new 2023 approach detailed in the preceding paragraphs, the "blank spots" have emerged in the database. Since the new Finance Sub-sub-index correctly assigns "n.a." values similarly to all other sub-sub-indexes, the "blank spots"

are also present in the final Geoeconomic Dependency Sub-index score.

We have decided to remove from the final sample the countries with "n.a." values for all the years included in the database (which in the past editions would have shown all "0" values), leading to the elimination of fourteen political entities (including the "Not classified" row, non-available by definition) form the final generic list of 266 names. Thus, the 2024 version of the Geoeconomic Dependency Sub-index contains thirteen less countries, but firstly, it is more accurate, since it does not assign a "no risk" value to a country for which there is no information available. Secondly, it does not significantly harm the comprehensiveness of the GRI Project, given the fact that, due to the previously explained peculiar characteristics of the countries with all "n.a." values, i.e. their size and status, they are not currently present in at least one other Sub-index as well (a fact confirmed through information sharing with other groups in charge of the other sub-indexes). Furthermore, leaving the countries in the final sample despite reporting all "n.a." values would have misrepresented the actual size of the Geoeconomic Dependency Sub-Index, without providing any value to the overall Geopolitical Risk Index, since the total lack of data of a country for any sub-index automatically excludes it from the final index.

In addition to the countries presenting "n.a." values across all years, there is a subset of nations which displays "n.a." values only for some years, as a consequence of the previously mentioned "spottiness" of the data. On one hand, leaving the "n.a." values in the final Geoeconomic Dependency Sub-Index score would have created a relevant issue for the Coordination Group, tasked with the calculation of the final Geopolitical Risk Index as a weighted average of the sub-indexes. The missing value would have led either to the complete removal of the country, substantially harming the geographical reach of the index, or to an imprecise calculation. On the other hand, removing the country directly at the Sub-Index level would have imposed a limiting factor on the potential final size of the GRI Project. Having in mind the key goal of expanding the Index both in time and space, we decided to apply an interpolation step to the data to replace the "n.a." values in the final Sub-Index score. Despite being conscious of the potential limitations connected with this approach, it is the only way

to avoid reducing the number of countries available and at the same time providing a more precise measure of Geoeconomic Dependency, compared to leaving the missing values in the dataset, or worse, assigning "0" (no risk) values. The decision to treat the data in order to avoid constraining the size of an Index, both in nations and years covered, is not unprecedented, both in the GRI Project and in other similar endeavours. For example, the Global Economic Diversification Index (EDI) published by the Mohammed Bin Rashid School of Government (MBRSG) is calculated by filling missing observations to tackle this specific problem, as stated in the Methodology paper.

For the countries with available data before the "n.a." value, we have calculated the Geoeconomic Dependency Score with the Excel function "Forecast.linear", which uses a linear regression based on past data to predict future values. For the countries missing past values, we have assigned the value of the closest available year. Despite introducing a degree of subjectivity in the calculation of the final score, the impact of these assumptions is not particularly significant for the overall GRI, with two main motivations. Firstly, the number of approximated values is extremely limited compared to the overall size of the final database, both at Sub-Index level and even more considerably at Index level. Secondly, due to the previously mentioned specific features of the countries reporting "n.a." values, only a fraction of the countries in this already small subset will have available data for all the other sub-indexes, thus limiting the presence of approximated values in the final Index.

In conclusion, the error in the application of the new approach to missing values in the 2023 edition of the Geoeconomic Sub-Index has led to the problem of "n.a." values in the final sub-index score going unnoticed. Following the recalculations of the 2024 version, the issue has resurfaced, confronting us with the choice of how to improve the accuracy and reliability of the Sub-index without harming its size. Notwithstanding the potential limitations associated with the final approach chosen, we believe that the actions undertaken represent a balanced decision, delivering an improvement both in the precision and the actual extension of the database, compared to both the previous years and the alternative solutions available.

2 GEOECONOMIC DEPENDENCY SUB-SUB-INDEXES

2.1 Energy

The Energy Sub-sub-index required the only straightforward update process in the 2024 version of the Geoeconomic Dependency Sub-index. A high value for the Energy Dependency score, which can originate either from a significant reliance on imported fuel or a concentration of the nation's exports in the specific energy sector (or both), indicates that a country's economy sustains a high risk of:

a) being impacted by a change in how much fuel is able to input in the domestic economy thanks to other nations' exports (for Fuel Imports);

b) being impacted by a change in how much energy it can export to other countries, due to the lack of diversification in the country's exports categories and, in general, of its economy (for Fuel Exports).

An example of case a) is Pakistan, while a clear example of case b) is Qatar.

In the previous years the index was calculated from World Bank data using the formula:

$$Energy\ dependency = \frac{Fuel\ Exports}{Merchandise\ Exports} + \frac{Fuel\ Imports}{Merchandise\ Imports}$$

The rationale behind this choice, as explained in the original report (see Barbry et al., 2022), is the fact that relying on a net balance between imports and exports instead of a sum would have inevitably led to the loss of information on the dependency.

Excluding the change in the indexation method, which will be developed further in section 3.2, the main innovations are related to the addition of new years. Keeping the original sources (https://data.worldbank.org/indicator/TX.VAL.FUEL.ZS.UN and https://data.worldbank.org/indicator/TM.VAL.FUEL.ZS.UN for Exports and Imports respectively), we were able to include the year 2022, as well as values from 1962 to 2015 (the 2023 version had a limited time range of 2016 to 2020). Thanks to the clear construction of the sub-sub-index and the choice of the source for the raw data, we applied the straightforward process to all the years available in the original data set, reaching the total size of 61 years, compared to the previous 5. This represents an extremely significant tenfold increase in historical depth of the sub-sub-index.

2.2 Raw Materials

The Raw Materials Dependency Index mirrors an economy's vulnerability to the ebb and flow of raw materials and commodity markets. Similarly to the Energy and Food Sub-sub-indexes, the principle behind the Raw Materials Sub-sub-index is the analysis of the overall trade dependency, rather than simply determining a net balance. The adopted methodology adds together the raw material exports and imports instead of considering their difference. This approach quantifies the overall degree of a country's interdependence with the global raw material trade, not only its self-sufficiency.

A high-risk index in this context indicates that a country may be particularly exposed to external market dynamics, whether due to a large volume of imports, which could reflect a strong dependence on external resources, or a significant volume of exports, which could denote an economy too focused on a few primary goods. In both cases, the goal is to reveal an economy's susceptibility to fluctuations in the trade of raw materials, without providing a simple balance that could mask important dependency dynamics.

In previous years, the Raw Materials sub-sub-index was calculated by summing raw material exports and imports, each as a percentage of GDP, using data from WITS:

$$Raw\ Materials\ dependency = \frac{Raw\ Materials\ Exports}{GDP} + \frac{Raw\ Materials\ Imports}{GDP}$$

In the 2024 edition of the Index, we have decided to change the data source, basing our choice on several motivations, among which the availability of 2022 data and the goal of ensuring uniformity across the sub-sub-indexes. The same choice has been made also for the Food sub-sub-index, as detailed in section 2.3.

The previously used WITS classification for Raw Materials is quite broad, also encompassing categories of products already included in the Energy and Food Sub-sub-indexes. The transition to direct use of data from the World Bank Database provides the added bonus of a more granular classification of the products, which allows us to correctly separate the Raw Materials components and avoid double counting with other sub-sub-indexes. The new Raw Materials Sub-sub-index is composed by two categories: "Ores and Metals"

(https://data.worldbank.org/indicator/TX.VAL.MMTL.ZS.UN and https://data.worldbank.org/indicator/TM.VAL.MMTL.ZS.UN for Exports and Imports respectively) and "Agricultural Raw Materials" (https://data.worldbank.org/indicator/TX.VAL.AGRI.ZS.UN and https://data.worldbank.org/indicator/TM.VAL.AGRI.ZS.UN for Exports and Imports respectively), each of them being calculated with a revised formula:

$$Ores\ \&\ Metals\ dependency = \frac{Ores\ and\ Metals\ Exports}{Merchandise\ Exports} + \frac{Ores\ and\ Metals\ Imports}{Merchandise\ Imports}$$

$$Agricultural\ R.M.dep. = \frac{Agricultural\ R.M.Exports}{Merchandise\ Exports} + \frac{Agricultural\ R.M.Imports}{Merchandise\ Imports}$$

After calculating the indexed 0-10 score for each category, the final Raw Materials Sub-sub-index is calculated as a simple average of the two components, similarly to the Finance sub-sub-index:

$$Raw\ Materials\ Dependency = \frac{1}{2} * (\ Ores\ \&\ Metals\ dep. + Agricultural\ R.M.dep.\ )$$

The combination of "Ores and Metals" and "Agricultural Raw Materials" effectively encapsulates the essential components of raw materials instrumental to economic development and industrialization. It includes minerals, metals, ores, as well as wood, rubber, textiles, all commodities that are vital for infrastructure and manufacturing. Furthermore, the choice of the World Bank Database allows the possibility to use a new scaling unit: Merchandise Exports/Imports, rather than GDP as in the previous version. Merchandise Export/Imports is the unit also used *ab origine* in the Energy Sub-sub-index.

Summing up, this modifications bring several advancements to the Sub-sub-index:

1. **Access to Current Data**: At the moment of writing (April 2024), the WITS Platform still does not provide the 2022 data. Missing an entire year, and furthermore, the most relevant one, would have significantly damaged the reliability of the Geoeconomic Dependency Sub-Index. On the contrary, the World Bank Databases provides access to 2022 values.

2. **Framework Alignment and Consistency:** The alignment with the calculation approach of the Energy and Food sub-sub-indexes ensures methodological consistency across the whole database. The use of a common denominator, i.e. the scaling factor (Merchandise Exports/Imports) increases the comparability of the measures, enhancing the accuracy of the overall Sub-index. It is now possible to more precisely examine the different sides of economic dependency thanks to the harmonisation among the Import/Export based sub-sub-indexes.

3. **Data Extension and Standardization:** The source of our data has been unified for all the economic measures in the database. By sourcing data from the World Bank, we were able to extend the historical depth of the Sub-sub-indexes as far back as 1962 and up to 2022, broadening our analytical scope and enriching the database with a comprehensive temporal perspective.

4. **Granular Product Classification:** As previously anticipated, the other categories present in the UNCTAD "Raw Materials" classification (the standard used by WITS) include food products and fuels that are already analysed in the Food and Energy Sub-sub-indexes respectively. Therefore, the change of product classification at the numerator of the formula not only does not harm the significance of the Raw Materials Sub-sub-index, on the contrary, it provides an efficient solution to avoid double counting and duplicated data. This result is reinforced by the use of a single source (World Bank Database) with the same classification standard (SITC) for the Energy, Raw Materials and Food Sub-sub-indexes.

5. **Stronger Link to Economic Activity**: The use of Merchandise Exports/Imports as a scaling factor allows to remove the potential influences of the other economic activities included in the GDP calculation. A formula with an Import/Export related measure at the denominator as well as at the numerator provides a more accurate portrayal of the dynamics of the phenomenon under analysis, compared to the more general GDP. Furthermore, the presence in GDP calculations of both Exports and Imports, when the numerator is focused specifically on only of them at a time, could lead to potential distorting effects, especially in the presence of significant economic fluctuations.

Thanks to these improvements, we now offer an expansive view that covers 61 years of data, matching the significant time expansion achieved in the Energy Sub-sub-index. The geographical reach has also increased by 30 countries (comparison made for 2020, the last year of input data in the 2023 Geoeconomic Dependency Database). Additionally, we were able to address one of the limitations of the original Geoeconomic Dependency Sub-index explicitly identified by the authors in the 2022 paper (Barbry et al., 2022): the new Raw Materials Sub-sub-index is perfectly comparable with all the Import-Export based sub-sub-indexes in the Sub-index (Energy and Food), increasing the consistency and the reliability of the data.

2.3 Food

Before addressing the specifics of the Food Sub-sub-index, an important remark: despite being mentioned as "Agriculture" Exports and Imports, the data used by the previous groups actually referred to Food, as visible both by the source link provided (https://wits.worldbank.org/CountryProfile/en/Country/WLD/Year/2019/TradeFlow/EXPIMP/Partner/all/Product/16-24_FoodProd, although not functioning) and the 2023 version of the Excel database. The use of Food is also consistent with the rationale outlined in the original 2022 paper. As a consequence, in order to avoid any misidentification issues with the newly introduced "Agricultural Raw Materials" and to provide a more appropriate label, we have changed the name of the sub-sub-index form "Agriculture" to "Food".

The Food Sub-sub-index quantifies the dependency of a country's economy on food import or export. In the past editions of the Geoeconomic Dependency Sub-index the Agriculture (now Food) Sub-sub-index was calculated as follows:

$$Agriculture\ dependency = \frac{Agriculture\ Exports}{GDP} + \frac{Agriculture\ Imports}{GDP}$$

Following the approach used for the Raw Materials Sub-sub-index, we have modified both the source (https://data.worldbank.org/indicator/TX.VAL.FOOD.ZS.UN for exports, while for imports https://data.worldbank.org/indicator/TM.VAL.FOOD.ZS.UN) and calculation approach.

Therefore, the new formula for the Food sub-sub-index is consistent with the Energy and Raw Materials sub-sub-indexes:

$$Food\ dependency = \frac{Food\ Exports}{Merchandise\ Exports} + \frac{Food\ Imports}{Merchandise\ Imports}$$

On one hand, the origin of the data at the numerator has not changed compared to the previous iterations, since the World Bank uses estimates from the WITS platform from the Comtrade database, i.e. the source in the original 2022 version of the Index. On the other, there is a modification in the scaling unit, from GDP to % of Merchandise Exports/Imports. For the rationale behind the change of the source and formula, refer to chapter 2.2 (motivations for the Raw Material change).

The first component of the formula evaluates the portion of a nation's overall export earnings that is composed of food items, such as food and live animals, drinks and tobacco, oilseeds, and vegetable and animal fats. The economy of the nation may be primarily focused on exporting food items if this indicator has a high value, which could indicate a lack of export diversification. The second component, which is based on the same SITC categories, shows what proportion of a nation's imports are food items. An exorbitant percentage here implies that the country's food demands are mainly supplied by imports, which might create questions regarding food security and a country's susceptibility to changes in the price and availability of food globally.

Finally, the adoption of the World Bank data on Food imports and exports has guaranteed the utilisation of the most recent data available, including 2022, without changing the fundamental rationale behind the sub-sub-index. Similarly to Energy and Raw Materials, the Food Sub-sub-index now covers the full extent of the dataset from the World Bank, from 1962 to 2022, i.e. 61 years compared to the previous 5, with an addition of 35 countries (comparison for 2020). Furthermore, the sub-sub-index has been improved by changing the source and calculation method, increasing its consistency, and allowing for more precise cross-comparisons with the other sub-sub-indexes.

2.4 Technology

If a country possesses ample raw materials or fuel, it might seem logical to assume that it relies less on others for manufacturing goods. However, this assumption doesn't always hold true. Manufacturing goods requires a certain level of technological expertise. The more advanced a country's technology, the less dependent it becomes on external sources for production.

To gauge this technological advancement, we turn to the Global Innovation Index (GII). The GII is an annual ranking of countries by their capacity for, and success in, innovation, published by the World Intellectual Property Organization (WIPO). It was started in 2007 by INSEAD and World Business, a British magazine. Until 2021 it was published by WIPO, in partnership with Cornell University, INSEAD and other organizations and institutions

The GII is instrumental as it furnishes policymakers, businesses, and stakeholders with crucial insights into the innovation strengths and weaknesses of different countries. By pinpointing areas for enhancement and exemplary practices, the GII aids in crafting strategies to promote innovation, boost economies, and tackle global challenges. Moreover, it serves as a benchmarking tool for countries to monitor their progress in building innovation ecosystems and remaining competitive in the global arena.

The GII is computed as the average of the Innovation Input Index and the Innovation Output Index, each structured around distinct pillars.

Innovation Input Sub-Index: this section captures elements of the national economy that facilitate innovative activities, and comprises five pillars:

- Institutions
- Human capital and research
- Infrastructure
- Market sophistication
- Business sophistication

Innovation Output Sub-Index: this section denotes the outcomes of innovative endeavors within the economy, and comprises two pillars:

- Knowledge and technology outputs
- Creative outputs

While the Output sub-index encompasses only two pillars, its weight in calculating the overall GII scores equals that of the Input Sub-Index.

Thus,

$$GII = \frac{Innovation\ Output\ Score + Innovation\ Input\ Score}{2}$$

A higher GII score (ranging from 0 to 100) correlates with increased job creation and long-term economic growth prospects. Consequently, to assess technological dependency, following the original rationale in the 2022 paper, we compute the Technological Dependency Index as the complement of the GII.

Technological Dependency Index = 100 − GII

This index is then scaled from 0 to 10 to align with other sub-indexes.

Regrettably, in previous years, the process of standardizing of this index wasn't consistently executed, and without access to the original data, we had to retrieve it from the WIPO websites and reapply the standardization process. This effort not only ensured accuracy but also allowed for the inclusion of additional countries and years of data. Indeed, while last year students had been able to utilize data as far back as 2016, we have been able to retrieve the values from 2011 to 2023 from the WIPO website and from 2007 to 2010 from the INSEAD website.

From 2011 onwards, the index had already been scaled from 0 to 100, with the values distributed following a normal distribution. For this reason, after having computed our Technological Dependency Index, we opted to rescale the index values from 0 to 10 to align them homogeneously with the other sub-sub-indexes, thus minimizing the data loss.

The situation differed slightly for the values spanning 2007 to 2010. Because of the economic uncertainty following the financial crisis of 2007, INSEAD aggregated the years 2008-2009 and 2009-2010 in their reports. Therefore, we chose to use the GII values for 2008-2009 as a proxy for 2008, and those for 2009-2010 as a proxy for

2010. Consequently, data for 2009 was missing and inferred as the average between the 2008-2009 and 2009-2010 values. Moreover, until 2010, the GII values were scaled from 1 to 7. To address the differing scales, we first normalized the index values from 0 to 100 and then proceeded as usual. Given the absence of outliers in the overall sample (2007-2022) due to the structural calculation of the index, the new percentile indexation method described in chapter 3.2 was not needed.

Summing up, the improved version of the Technology Sub-sub-index covers significantly more years (i.e., 17 vs 7 in 2023), having used all the data available for the GII, an extremely relevant upgrade since this sub-sub-index represents the limiting factor in terms of historical depth for the overall Geoeconomic Dependency Sub-Index. Furthermore, it covers 14 more countries (comparison for the year 2020) and it is substantially more transparent in its calculations in the Database.

2.5 Finance

The Finance Sub-sub-index represented a challenging task in the innovation process for the 2024 version of the Geoeconomic Dependency Sub-index. The key issue was the complete absence of evidence of the raw data to final scores transformation process, with the Excel dataset including only pasted final grades for the years 2016 – 2020 for the usual 266 countries/geographical entities of the World Bank datasets. The only guide available is the 2022 Geoeconomic Dependency Report, which provides the calculation formulas for the sub-sub-index:

$$Debt - linked\ dependency = \frac{\%\ of\ debt\ owned\ by\ foreign\ entities}{GDP}$$

$$FDI - linked\ dependency = \frac{net\ FDI\ inflow}{GDP}$$

$$Financial\ dependency = \frac{1}{2} * (Debt - linked\ dependency + FDI - linked\ dependency)$$

The Debt-linked dependency measures how much a nation relies on foreign entities to

finance its economy, possibly leading to external pressures, originated either by shocks or as instruments of Geopolitical strategy. On the other hand, a high score in Foreign Direct Investment (FDI)-linked dependency evaluates the risk of a country's economy to be impacted by investment decisions being taken by foreign actors.

The inferred original process consisted of 3 steps:

1. Retrieving the Debt-linked dependency and FDI-linked dependency data;
2. Indexing the data:
   a. Debt-linked dependency: "*Iran has the least foreignly owned public debt (2.7%/GDP) and so receives a score of 1 out of 10, and the highest foreignly owned countries (7 of them above 150%/GDP) receives a score of 10. So, it gives us a scale where you gain 1 point every 15%/GDP*" (Original example quoted in the 2022 Report);
   b. FDI-linked dependency: "*We gave 1 for every country below 1% of FDI/GDP and increase by 1 point for every 1% of FDI/GDP more.*" (Quotation from the 2022 Report);
3. Calculating the final Financial dependency grade as an average of the Debt-linked dependency and FDI-linked dependency indexed scores.

While the FDI-linked dependency values can be easily found following the link to the World Bank website present in the original 2022 Report (https://data.worldbank.org/indicator/BX.KLT.DINV.WD.GD.ZS), the same is not possible for the Debt-linked dependency. The original links provided led either to a generic page and not a specific index (for the International Debt Statistics by the World Bank), or they led to a "Page Requested Not Found" (for the Sovereign Debt Investor Base for Advanced Economies published by the IMF). The data relative to the Sovereign Debt Investor Base for Advanced Economies published by the IMF that we were able to find using an independent search only included 24 countries.

The lack of clear and complete sources, combined with the absence of any transparent indication on how to merge the IMF and World Bank data – due to the presence of

only pasted final grades for the general Financial dependency in the Excel database – led to the decision to change the source for the Debt-linked dependency values. With the goal of avoiding any significant change in the original rationale adopted by the 2022 Group, in the 2024 version we employ the World Bank International Debt Statistics estimates for the External debt stocks, total, DOD, current US$ (https://data.worldbank.org/indicator/DT.DOD.DECT.CD) combined with the World bank GDP estimates, current US$ (https://data.worldbank.org/indicator/NY.GDP.MKTP.CD), to calculate the Debt-linked dependency as:

$$Debt - linked\ dependency = \frac{External\ debt\ stock}{GDP}$$

Since the External Debt stock is equivalent to the amount of debt owed to nonresidents (as per World Bank definition) and the scaling is with respect to GDP as per the original formula, the only change made was the discontinuation of the Sovereign Debt Investor Base for Advanced Economies published by the IMF in favour of the use of the International Debt Statistics from the World Bank, already listed among the original sources, despite the link being not directly connected to the specific index.

Following the approach adopted for all the other sub-sub-indexes, the indexation method was modified, as detailed in section 3.2. The new process for calculating the Financial dependency Sub-index is detailed as follows:

1. Retrieving the External Debt Stocks, GDP, Net FDI Inflows as % of GDP data, all from the World Bank links provided;
2. Calculating the percentage of debt owned by foreign entities by dividing the External Debt Stock by the GDP;
3. Indexing the data, following the percentile method as explained in section 3.2;
4. Calculating the final Financial dependency grade as an average of the Debt-linked dependency and FDI-linked dependency indexed scores.

In conclusion, the update process of the Finance sub-sub-index provides several significant improvements, while at the same time leaving untouched the fundamental reasoning behind the original construction in the 2022 version. Firstly, it is now possible to follow a clear path from raw data to final scores thanks to the inclusion of formulas and calculations in the Excel database, enhancing the overall transparency and usability. Secondly, the sources of data for the current version are explicit and easily available for further update in the future. Finally, not considering the geographical reach (as explained in section 1.2., it is impossible to estimate how many countries were missing values in the original version of the Finance sub-sub-index), it was possible to expand the time range from the usual 2016-2020 to the new 1970-2022 historical depth.

2.6 Foreign Aid

The Foreign Aid Sub-sub-index measures a country's dependence on foreign aid for its own development. In the years 2022 and 2023, this index was measured using the following formula:

$$Foreign\ Aid\ dependency = \frac{Net\ ODA}{Central\ Government\ Expense}$$

Official Development Assistance (ODA) is defined as government aid designed to promote developing countries' economic development and welfare. A high foreign aid dependency index indicates a country that is heavily reliant on foreign assistance for the survival and expansion of its own economy.

In the new version of the Sub-index, we have the decide to change the method of calculating the sub-sub index:

$$Foreign\ Aid\ dependency = \frac{Net\ ODA}{Gross\ National\ Income}$$

Below are the main reasons why we took the decision to shift towards this new definition:

1) **Greater availability of data by number of countries**: using such index from the World Bank database https://data.worldbank.org/indicator/DT.ODA.ODAT.GN.ZS we are able to achieve a goal set by the group work assignment: improve the data from a geographical reach standpoint. In the previous version (% of Central Government Expenses) only n. 72 values are available from the World Bank dataset for year 2020, while applying this change, n. 174 nations have available data.

2) **Comprehensive Measure of National Economy**: GNI includes not only the total income generated within a country from a geographical point of view (within the country's borders) but also income earned by residents abroad. This provides a more comprehensive picture of a nation's economic capacity while central government expenses only reflect a portion of the economy.

3) **Economic Strength**: GNI better reflects the overall economic strength of a country's economy, including its capacity for self-sufficiency and its ability to generate resources internally. It gives a better indication of a country's ability to fund its own development initiatives and hence reduce dependence on foreign aid.

4) **Less Susceptible to Fluctuations**: Central government expenses can be highly variable, influenced by political decisions and economic conditions. GNI, on the other hand, tends to be more stable over time.

5) **Comparable Across Countries**: GNI allows for better comparisons of foreign aid dependency between countries with different levels of government expenditure.

Finally, as far as the development of the index on a time basis is concerned, because of the database updates, it was possible to include actual data (and no longer an arbitrary approximation) for the year 2021 and 2022. At the same time, past years up to 1962 were added, whereas in previous work the data did not go beyond the year 2016. While historical depth increased by more than tenfold, similarly to other sub-sub-indexes, the geographical reach was extended as well by more than 140%, thanks to the innovations put in place.

3 GENERAL IMPROVEMENTS

3.1 Structure of the Database

3.1.1 Sources and Data Input

The Excel file containing the 2023 Database of the Geoeconomic dependency Sub-index presented some problems, the major one being a strong difficulty in interpreting the data caused by a lack of reference to the sources of the reported calculated values. Only for the Energy Sub-sub-index it was clearly and correctly showing the entire raw data-calculation-indexation process.

To make the database more usable and facilitate the development of the Geopolitical Index in the coming years, we have taken the following corrective measures:

- In each sub-sub index sheet, a direct link to the source of the data has been inserted. From the above-mentioned link, it is possible to download the database from which the data was taken and check the correspondence.
- For each sub-sub index, 'raw data' from the source was entered. In some cases, in the previous year's work, indexed calculated values were reported directly. The absence of a direct reference to the specific source or calculation and indexation methods, could have significantly harmed and slowed down the forthcoming update processes.

3.1.2 Formulas Adjustments

In the Geopolitical dependency index 2023 database, a further problem was caused by the scarcity of formulas in the excel file. Most of the values were simple "copy and paste". This caused difficulty in interpreting the data and understanding the links between the different sub-sub-indexes.

With the aim of making a general improvement to the database, we have corrected and implemented the following formulas:

- Each sub-sub index sheet now includes formulas linking the raw data to the calculation of the final value before indexing, according to the formulas established by previous reports.

- Each sub-sub index sheet now includes the correct formulae for deriving the indexed values.
- The "Final sub-index summary" sheet now presents the correct references to the data for each sub-sub index, along with the formulas for calculating the overall grade.

3.2 Method of Indexation

Following the extraction of the raw data and the calculation of the Sub-sub-indexes values, the final significant step is to convert the values from their original unit of calculation (e.g., % of Exports or GII score) into a 0 to 10 score, in order to allow comparability across the overall Geopolitical Risk Index.

In relation to this process, the 2024 version of the Geoeconomic dependency Sub-index includes a significant change from the previous years: the indexing method has been completely revised and improved.

3.2.1 Motivation

The main reason for the change is that the indexing method used in the 2022 and 2023 versions was negatively affected by the distribution of data and the presence of outliers. In particular, a country displaying a significantly high figure in the raw data would have resulted in a substantial part of the sub-sub-index with indexed values close to zero.

The problem lies in the "old" indexation formula, which doesn't account for the distortion caused by outliers:

$$Indexed\ Value = \frac{10 * Raw\ Value}{MAX - MIN}$$

A maximum with an extremely high value relative to the average of the other data points would cause the distribution of the indexed values to be pushed very close to 0. The effects of this distortion are clearly visible in the 2023 Excel Database, where the final grades for the Agriculture (named as "Food" in the Excel) and Raw Materials

Sub-sub-indexes present averages well below 0.5. As a consequence, when calculating the Geoeconomic Dependency as an equally weighted arithmetic average of the Sub-sub-indexes, two values approximately equal to 0 were added, while at the denominator the division was still by 6. The result is a very low Final Grade for the Sub-index, caused by few extreme outliers in the Sub-sub-indexes, which harms its overall significance and comparability with the other Sub-indexes.

In conclusion, using the same indexation formula in the 2024 Database would have resulted in a Sub-Index with inconsistent values, potentially damaging the relevance of the analysis not only for the Geoeconomic Sub-Index, but also of the final Geopolitical Risk Index.

3.2.2 Calculation Process of the New Indexation Method

The new approach to the indexation process works as follows:

i. For each year of each sub-sub index, 21 percentiles are calculated (0, 5%, 10%, … , 100%);

ii. A score from 0 to 10 is assigned to each percentile (e.g., 5th percentile - 5% - corresponds to a score of 0.5), with the minimum value of the distribution receiving a score of 0 and the maximum a score of 10;

iii. A Vlookup formula is used to identify the percentile value closest to each unindexed raw value;

iv. The corresponding 0-10 score is assigned to the raw value to provide the final indexed value.

3.2.3 Rationale and Results

The process of choosing a new indexation method required considering several options, among which the possibility of removing the outliers, either singularly or identifying an "exclusion zone" for the values above some k-th percentile (e.g., 95th). Following careful consideration, we have decided for the Percentile Indexation method detailed in chapter 3.2.2., which provides several advantages:

1. **Avoid exclusion of available data:** The approach adopted in our version of the Sub-index allows to prevent the elimination of valuable data points, which would have been discarded in case of direct removal of outliers. Given the importance of expanding as far as possible the geographical reach of our Sub-index, excluding available data would have been inconsistent with our goals.

2. **Provide a complete picture of Geoeconomic Dependency:** On one hand, removing the outliers would have solved the numerical distortion, however it would have caused an equally significant misrepresentation. The final Index would have portrayed an incomplete picture, a world were extremes do not exist. Given the complexity of our society, it is highly relevant to correctly identify and present the extremes up to which a phenomenon can arrive.

3. **Utilize a consistent method:** The percentile indexation leaves no space to arbitrary judgement, providing a coherent approach to all data across the sub-sub-indexes, instead of singularly and subjectively identifying the outliers.

4. **Application of a proven approach:** The use of percentiles to tackle the problem of outliers is not unprecedented in the Geopolitical Risk Index, with the Globalization Sub-Index using it since 2022 (Sarucanian et al., 2022). The similarity of the original raw data (i.e. a large dataset including more than 200 countries with sub-sub-indexes including import/export data) provides an additional motivation for its employment in the Geoeconomic Dependency Sub-index. However, we have adopted a slightly different approach, deciding to double the number of percentiles (from 11 to 21) in order to increase the granularity and representativeness of the scores.

Looking at the final Geoeconomic Dependency 0 to 10 scores, it is possible to conclude that the distortion caused by the outliers is no longer present, resulting in a more comparable and meaningful risk index.

4 LIMITATIONS

While representing a significant advancement for the Geoeconomic Dependency Sub-Index, our work is still affected by some limitations and areas for future development.

From the historical depth point of view, the Sub-Index is constrained by the Technology Sub-sub-index, which does not go beyond 2007. In addition, the 2007-2010 values were not consistently provided by the source compared to the following years, which led to some approximations. Having exhausted all the available data from the Global Innovation Index, future updates of the Database could use a different source in order to expand the analysis further back in time.

An additional drawback of the Sub-index can be traced back to the original structure of the Import/Export and Finance based sub-sub-indexes. Despite providing a clear and meaningful overview of the dependency of a country towards the overall world economy (declined in its main components, e.g., Food, Energy, Raw Materials, etc.), these measures do not explore the bilateral interconnections among nations. For example, a country with 50% of its export being related to fuels is riskier than a country with a more diversified export base, but that 50% could hide a much higher level of risk if related mainly to a single trade partner. Having established a solid base in the 2024 edition, which speeds up considerably the updating process of the existing sub-sub-indexes, future developments could focus on the introduction of a risk adjustment measures or an entirely new subindex to assess the degree of diversification among trade partners for each specific country.

Last but not least, the main limitation of the Geoeconomic Dependency Sub-Index is connected with the "blank spots" in the database thoroughly explained in chapter 1.2. This feature has led to forced trade-off decisions between the accuracy and the size of the Sub-Index. Despite being able to provide a more reliable measure already from this version, forthcoming improvements could focus on this crucial area, leveraging more advanced interpolation techniques or other approximation processes.

5 CONCLUSIONS

The 2024 edition of the GRI Project was centered on a key guideline: expand the Index across the temporal and geographical dimensions. The 2024 Geoeconomic Dependency Sub-sub-index represents a significant advancement in both.

Considerable progress has been made in the historical depth of the Geoeconomic Dependency Sub-index. The increase in the number of years, from 5 (only 2016-2020, given the fact that the year 2021 was approximated with calculations) to 16 (2007-2022), represents a substantial improvement, especially considering the relevance of providing accurate updated data. The GRI Project will now be able to rely on actual values for 2021 also for the Geoeconomic Dependency Sub-index, resulting in a completely genuine risk index. Moreover, the decision to use the World Bank as main source for the raw data, has allowed us to conveniently calculate values for some Sub-indexes as far back as 1962 (Energy, Raw Material, Food, Foreign Aid) or 1970 (Finance). This depth provides a solid starting point for future students to develop on.

Regarding the geographical reach, we focused our effort on keeping the pre-existing extensive size of the Index while implementing the other modifications and improvements. Of the 266 countries and geographical entities forming the World Bank database, only 14 of them present "n.a." values in all the years across which the Geoeconomic Dependency Sub-index spans. In the 2023 edition these countries presented incorrect values due to a calculation error, as explained in section 1.2, thus generating no impairment with their removal. At the end of the process, our Sub-Index covers 252 countries and geographical entities, posing no limitation in this sense to the Geopolitical Risk Index. Furthermore, we have introduced significant improvements at sub-sub-index level, especially for Foreign Aid, where previous editions covered only a small part of the dataset.

In addition to the expansion across time and geography, our goals for the 2024 version of the Geoeconomic Dependency Sub-index included a further important point: increasing the accuracy, readability and transparency of the Database. Creating a more

accessible and usable Sub-index is important not only for the current year, but also for all the forthcoming editions of the GRI Project. By saving time in understanding the functioning of the database, future students will be able to focus on the update and improvement process, as anticipated in Chapter 4.

The first step toward a new improved Sub-Index was the rectification of two inaccuracies in the previous versions of the database, followed by a complete renovation of the Excel file. Furthermore, the current version provides a complete step by step calculation process, starting from the links to the original sources, passing by the raw data and formulas, and ending with the indexed final scores. The structure of the spreadsheet has been streamlined to guarantee ease of update and legibility. The change in scaling unit for two of the sub-sub-indexes has addressed a relevant limitation described in the original report, i.e. the lack of comparability among the Import/Export based measures. Finally, we have adopted a new indexation method that successfully resolves the underestimation problems caused by the outliers in the dataset.

In conclusion, the 2024 Geoeconomic Dependency Sub-index has addressed several of the issues present in the past editions, substantially increasing at the same time its size and reliability. The new Sub-Index is broader, more accurate, easier to comprehend and update. While certainly some limitations and avenues for further development remain, a significant step has been made towards the improvement of the Geopolitical Risk Index Project.

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