CHAPTER 3

FRAGMENTATION AND COMMODITY MARKETS: VULNERABILITIES AND RISKS

Online Annexes

Online annexes 3.1.–3.6. present the data sources, additional stylized facts, methodology and complementary results referenced in the main text. Further details are in Alvarez and others (2023).

Online Annex 3.1 Data Sources, Sample Coverage, and Variable Definitions

Data sources are described below, while the list of economies included in the main exercises and country composition of blocs in the baseline scenario are provided in Annex Table 3.1.1.

3.1.1. Data Sources and Main Data Series

The chapter uses a new annual dataset on bilateral trade flows and production of 48 commodities at the country level based on Alvarez and others (2023). The energy (coal, natural gas, and crude oil), mineral, and agricultural commodities included are listed in Alvarez and others (2023) and Online Annex Figure 3.2.1. They were selected because they represent a large share of global trade or are part of critical raw materials lists by the EU or US. Commodities with insufficient data were eliminated from consideration (e.g., uranium).

Starting from the methodology of Fally and Sayre (2018) and updated by Bolhuis and others (2023),[1] the dataset was created with three key innovations. First, a new set of adjustment factors corrects for different unit measurements for mineral commodities in the production and trade data based on information from the British Geological Survey, the German Mineral Resources Agency, and other sources. The different unit measurements are often overlooked in the trade literature. For instance, some minerals are expressed in metric tons of metal content in the production database, while their counterparts are presented in gross metric tons in the trade database. The factors convert the quantities in the trade data into equivalent metric tons of metal content. These adjustment factors can be commodity- and country-specific. The reader is referred to Alvarez and others (2023) for further details.

The second innovation is that the dataset includes the markets for mined upstream commodities (e.g. copper ore) and refined commodities (e.g. refined copper). Distinguishing between the different products along the value chain can lead to distinctly different production concentrations and trading patterns. The production and trade data for refined commodities also include recycled materials with the exception of aluminum.

Third, the production and trade data are linked through new manually constructed concordances between HS codes and commodity production definitions. The dataset first took

[1] We thank Thibault Fally and James Sayre as well as Marijn Bolhuis, Jiaqian Chen and Benjamin Kett for sharing data and related code with us.

the concordances between minerals trade and production data from Fally and Sayre (2018) and Bolhuis and others (2023) as a starting point. The concordances were then further developed based on consultations with the British Geological Survey (BGS) as well as the commodity-specific industry literature (for example, DERA (2023) and others; see Alvarez and others (2023) for further details and the mapping tables). For agricultural and energy commodities, the dataset relies on concordances from the Food and Agriculture Organization (FAO) and the International Energy Agency (IEA), respectively.

Bilateral trade data for minerals are from the Bilateral Commodity Trade Database (BACI), which draws on UN Comtrade. For agriculture, data are from FAO's trade matrix database.[2] Both sets provide standardized data on bilateral trade flows at the HS 6-digit product level, covering the 1986-2022 period, 220 countries and 49 commodities.

Production data for minerals are from the BGS, except for titanium, silicon, and potash, for which we use the US Geological Survey (USGS) data. Production of some minerals is expressed in metric tons of metal content, while trade data are reported in metric tons.

For agricultural commodities, output data are from the FAO Crops and Livestock Products Dataset, supplemented with the FAO Supply Utilization Accounts Dataset for rice and sugar. Energy commodities data is sourced from the International Energy Agency (IEA).

Cross-country Mergers and Acquisitions (M&A) are from Refinitiv Eikon.

Greenfield Foreign Direct Investment (FDI) data are from fDi Markets, a service offered by the Financial Times. The database tracks and records new physical projects or the expansion of pre-existing investments using primarily public sources, such as media reports, industry organizations, investment promotion agencies, and news wires.

Commodity price data for mineral and energy commodities are sourced from Bloomberg L.P., a global financial data provider. For agricultural and some mineral commodities, we calculate export prices using monthly trade quantity and value data from UN Comtrade. We estimate exports based on reported imports from trade partners (mirroring) to improve data coverage and quality.

Price elasticities of supply and demand are from Fally and Sayre (2018) and Dahl (2020), who provide a literature review of commodity elasticity estimates. The elasticities used in the chapter and their sources are reported in Alvarez and others (2023).

3.1.2. Economies Included and Definition of Blocs

The chapter includes all IMF World Economic Outlook economies for the exercises. If data is not available for a specific commodity in an exercise, the country is dropped from the sample. The countries are listed in Online Annex Table 3.1.1.

[2] We apply the common mirroring technique to FAO bilateral trade data to calculate country specific exports based on reported imports from partner countries. This involves setting the exports from country "i" to country "j" equal to the imports of country "j" from country "i," thereby rectifying the mismatch and ensuring data consistency.

The baseline scenario divides countries into two hypothetical geopolitical blocs, based on the March 2022 UN vote on the war in Ukraine (see Online Annex Table 3.1.1.). Countries which abstained in the vote, are assigned to the China-Russia+ bloc. Different bloc configurations are also considered (Online Annex Table 3.5.1.).

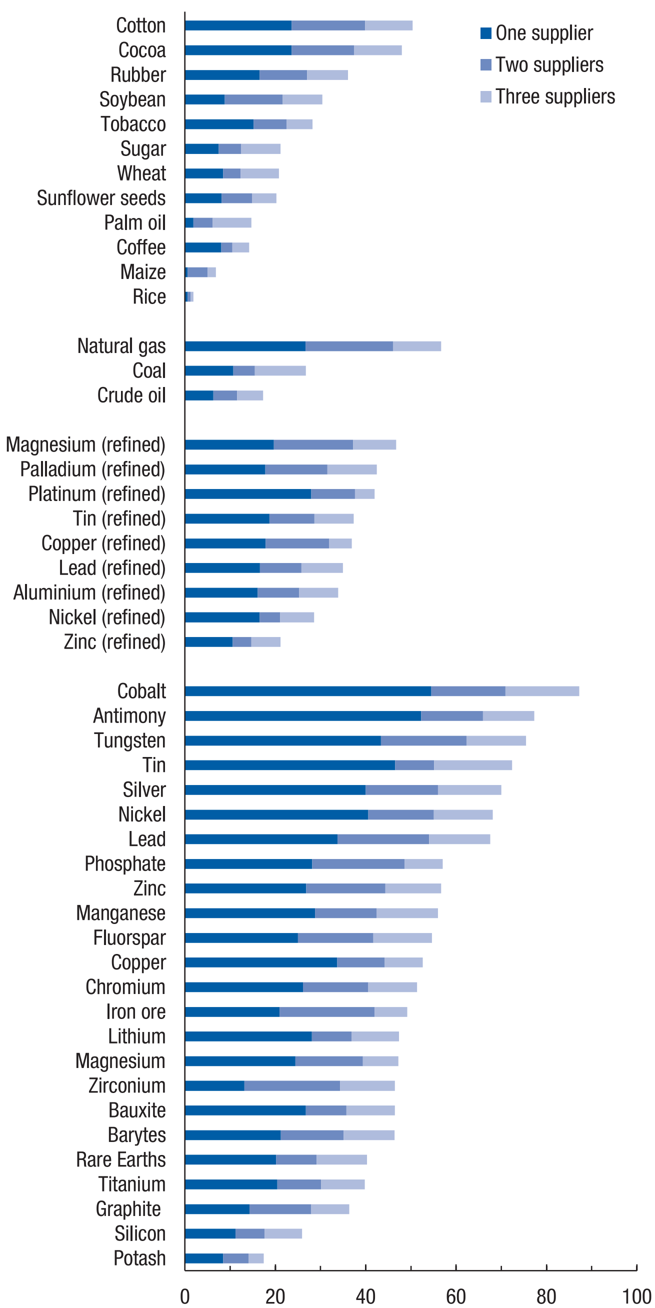
Online Annex Table 3.1.1. Economies Included and Baseline Scenario Bloc Composition

US-Europe+ Bloc	China-Russia+ Bloc
Afghanistan; Albania; Andorra; Antigua and Barbuda; Argentina; Aruba; Australia; Austria; Bahamas, The; Bahrain; Barbados; Belgium; Belize; Benin; Bhutan; Bosnia and Herzegovina; Botswana; Brazil; Brunei Darussalam; Bulgaria; Cabo Verde; Cambodia; Canada; Chad; Chile; Colombia; Comoros; Congo, Democratic Republic of the; Costa Rica; Côte d'Ivoire; Croatia; Cyprus; Czech Republic; Denmark; Djibouti; Dominica; Dominican Republic; Ecuador; Egypt; Estonia; Fiji; Finland; France; Gabon; Gambia, The; Georgia; Germany; Ghana; Greece; Grenada; Guatemala; Guyana; Haiti; Honduras; Hungary; Iceland; Indonesia; Ireland; Israel; Italy; Jamaica; Japan; Jordan; Kenya; Kiribati; Korea; Kosovo; Kuwait; Latvia; Lebanon; Lesotho; Liberia; Libya; Lithuania; Luxembourg; Malawi; Malaysia; Maldives; Malta; Marshall Islands; Mauritania; Mauritius; Mexico; Micronesia; Moldova; Montenegro, Rep. of; Myanmar; Nauru; Nepal; Netherlands; New Zealand; Niger; Nigeria; North Macedonia; Norway; Oman; Palau; Panama; Papua New Guinea; Paraguay; Peru; Philippines; Poland; Portugal; Puerto Rico; Qatar; Romania; Rwanda; Samoa; San Marino; São Tomé and Príncipe; Saudi Arabia; Serbia; Seychelles; Sierra Leone; Singapore; Slovak Republic; Slovenia; Solomon Islands; Somalia; Spain; St. Kitts and Nevis; St. Lucia; St. Vincent and the Grenadines; Suriname; Sweden; Switzerland; Thailand; Timor-Leste; Tonga; Trinidad and Tobago; Tunisia; Türkiye; Tuvalu; Ukraine; United Arab Emirates; United Kingdom; United States; Uruguay; Vanuatu; Yemen; Zambia	Algeria; Angola; Armenia; Azerbaijan; Bangladesh; Belarus; Bolivia; Burkina Faso; Burundi; Cameroon; Central African Republic; China; Congo, Republic of; El Salvador; Equatorial Guinea; Eritrea; Eswatini; Ethiopia; Guinea; Guinea-Bissau; Hong Kong SAR; India; Iran; Iraq; Kazakhstan; Kyrgyz Republic; Lao P.D.R.; Macao SAR; Madagascar; Mali; Mongolia; Morocco; Mozambique; Namibia; Nicaragua; Pakistan; Russia; Senegal; South Africa; South Sudan; Sri Lanka; Sudan; Syria; Tajikistan; Tanzania; Togo; Turkmenistan; Uganda; Uzbekistan; Venezuela; Vietnam; Zimbabwe

Source: IMF staff compilation.

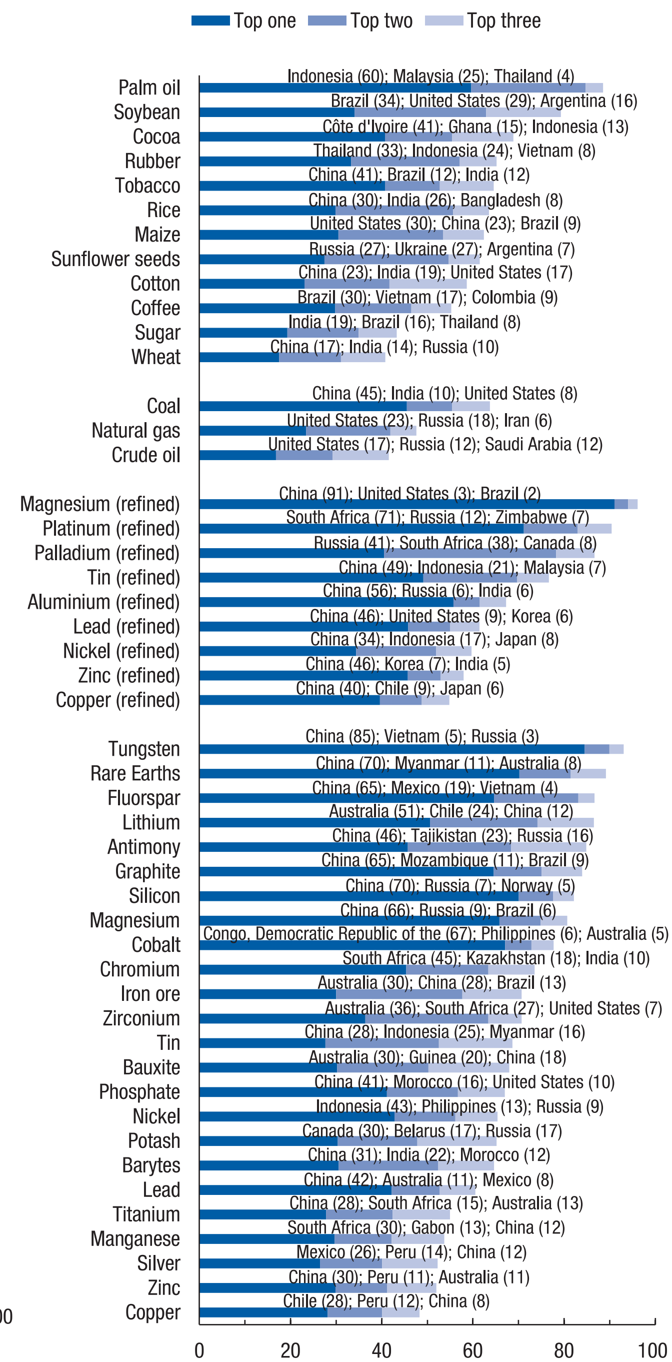
Online Annex 3.2. Additional Stylized Facts

Online Annex Figure 3.2.1. Share of Countries that Import from Only One, Two, or Three Suppliers
(Percent)



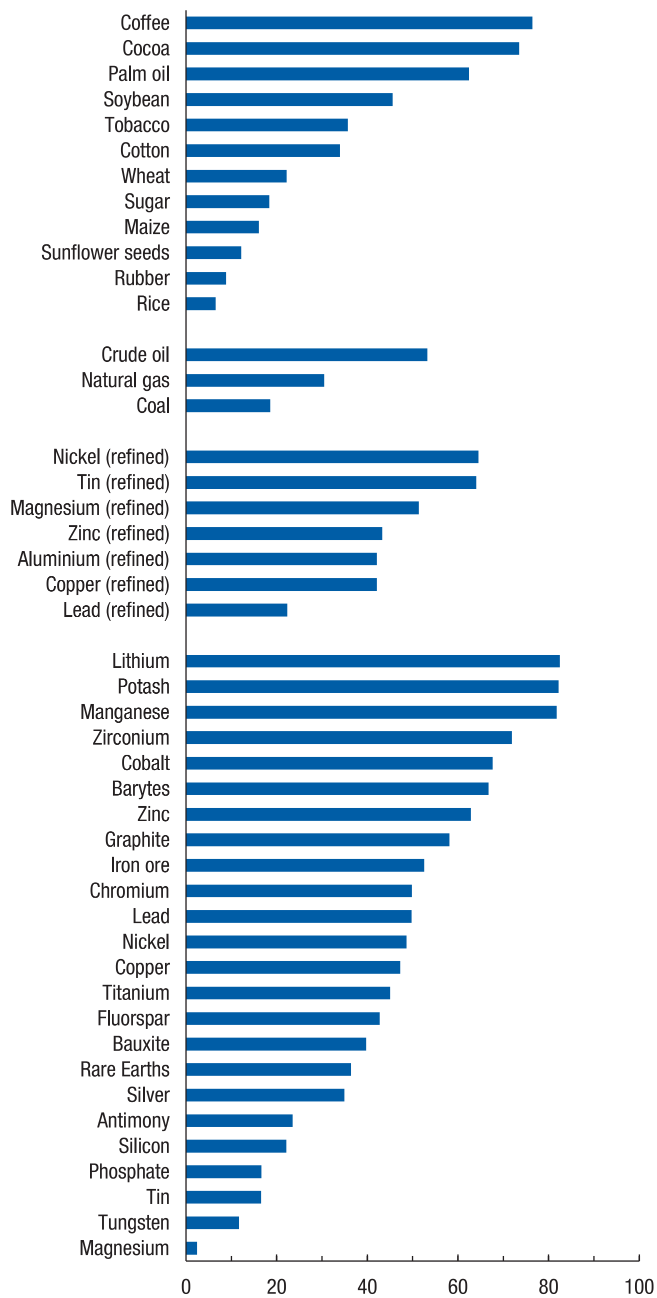
Sources: British Geological Survey; Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.

Online Annex Figure 3.2.2. Share of Top Three Countries in Total Commodity Production
(Percent)



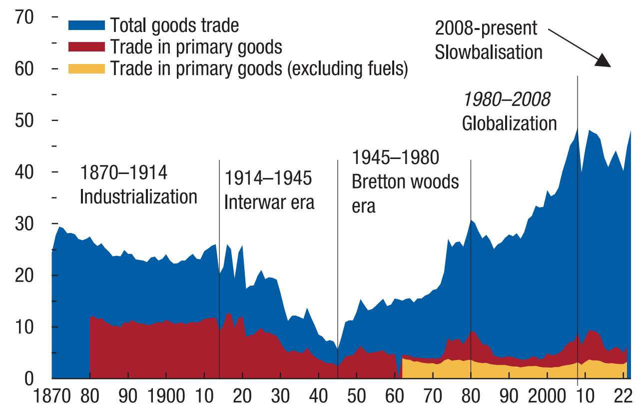
Sources: British Geological Survey; Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.

Online Annex Figure 3.2.3. Share of Traded World Production
(Percent)



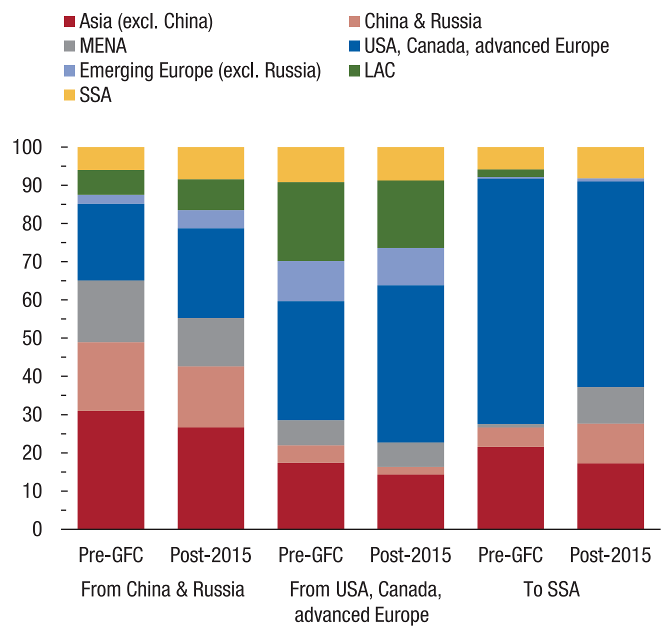
Sources: British Geological Survey; Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.

Online Annex Figure 3.2.4. Total and Primary Trade Openness
(Sum of goods exports and imports, percent of GDP)



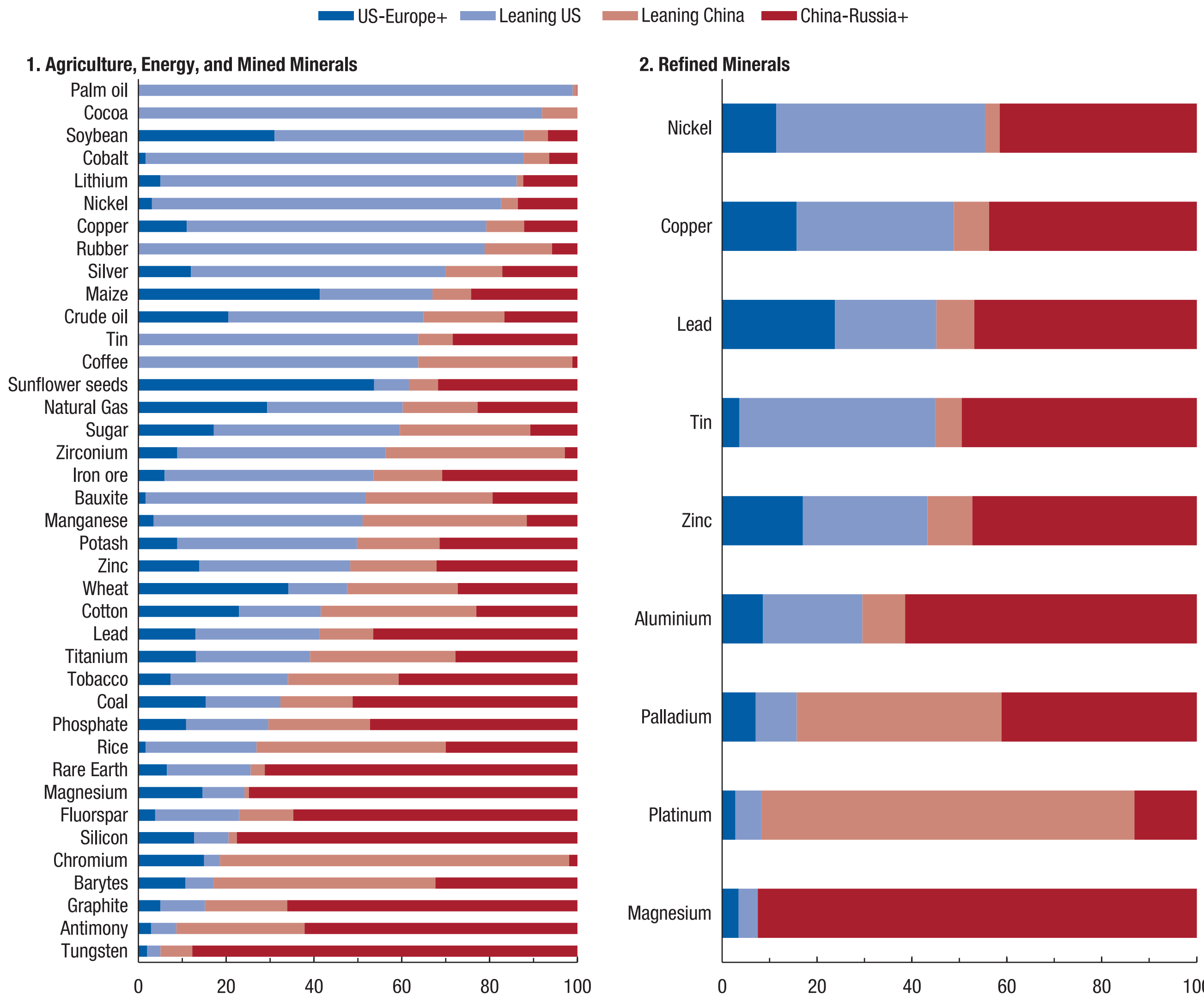
Sources: International Trade Statistics, 1900-1960; Jacks and Tang (2018); Jordà-Schularick-Taylor (JST) Macrohistory Database; UN Comtrade; and IMF staff calculations.
Note: Trade openness is measured as the ratio of exports and imports to GDP in nominal USD. Commodity trade is approximated by primary goods trade, using the Broad Economic Classification (BEC) Rev. 1. UN Comtrade data (1962-2022) is spliced with series from the UN International Trade Statistics, the JST Macrohistory database, and Jacks and Tang (2018).

Online Annex Figure 3.2.5. Greenfield FDI and M&As in the Commodities Sector: Selected Sources and Destinations
(Percent of projects)



Sources: fDi Markets; and IMF staff calculations.
Note: FDI = foreign direct investment; GFC = global financial crisis; LAC = Latin America and the Caribbean; M&As = mergers and acquisitions; MENA = Middle East and North Africa; SSA = sub-Saharan Africa.

Online Annex Figure 3.2.6. Commodity Global Production: Distribution across Blocs
(Percent of global production, 2019)



Sources: British Geological Survey; Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.

Online Annex 3.3. Gravity Equation Exercise

To estimate the gravity equation that relates geopolitical distance to bilateral commodity trade, bilateral trade values from BACI and FAO are used. Other gravity covariates, such as geographical distance between pairs of countries, common language, among others, are obtained from CEPII GeoDist database (Mayer and Zignago, 2011). The Alliance Treaty Obligations and Provisions (ATOP) database (Leeds and others, 2002) provides information on each country's portfolio of military alliances. ATOP is used to calculate the similarity of portfolios of each country pair following Signorino and Ritter's (1999) s-score, s_{ijt}, for country i and country j in year t. The measure of distance of military alliances is $MD_{ijt} = 1 - s_{ijt} \geq 0$. For ease of interpretation, MD_{ijt} is normalized so that its standard deviation is 1 in every year.

The gravity equation is estimated for each commodity type using 2010-18 data according to

$$y_{cijt} = \alpha_c MD_{ijt} + \beta_c X_{ijt} + E_{cit} + I_{cjt} + \varepsilon_{cijt}$$

where y_{cijt} is the value of exports of commodity type c from country i to country j in year t. Gravity covariates, X_{ijt}, include the geographical distance between the most populated cities in a country pair; whether countries are contiguous; speak a common language; have a colonial relationship; share a colonial history; are a current colony; and whether either country is a member of the World Trade Organization.[3] E_{cit} and I_{cjt} are fixed effects that capture importer- and exporter-specific trends in the trade of commodity c.

To account for country pairs having no trade flows in specific commodities, y_{cijt} is measured as an inverse hyperbolic sine of the trade value.[4] Two other specifications are run for robustness, where the gravity equation is estimated as a Poisson regression. The first specification is

$$v_{cijt} = \exp\left(\alpha_c MD_{ijt} + \beta_c X_{ijt} + E_{cit} + I_{cjt} + \varepsilon_{cijt}\right).$$

The second specification follows Hakobyan and others (2023) and first estimates the *undirected* propensity that a country pair trades goods, δ_{cijt} such that $\delta_{cijt} = \delta_{cjit}$ for any i, j

$$v_{cijt} = \exp\left(E_{cit} + I_{cjt} + \delta_{cijt} + \varepsilon_{cijt}\right),$$

and in a second stage estimates how distance of military alliances can impact this propensity

$$\delta_{cijt} = \alpha_c MD_{ijt} + \beta_c X_{ijt} + u_{cijt}.$$

The regression results can be found in Online Annex Table 3.3.1. Across all specifications, military distance is negatively associated with commodity trade flows. There are differences in the strength and consistency of this association across commodity types, with the negative effect of geopolitical distance on trade typically being the most pronounced for minerals.

Online Annex Table 3.3.1. Gravity Equation Coefficients on Military Distance

Specification	Commodity Type			
	All Commodities	Agriculture	Energy	Minerals
	(1)	(2)	(3)	(4)
Baseline (inverse hyperbolic sine)	–0.2306***	–0.2298***	–0.1532***	–0.3789***
	(0.0372)	(0.0376)	(0.0259)	(0.0416)
Poisson (one stage)	–0.151	0.1052**	–0.4492***	–0.2449***
	(0.1007)	(0.053)	(0.1499)	(0.0716)
Poisson (two stages)	–0.1186*	–0.0558	–0.0957	–0.1575***
	(0.0621)	(0.0418)	(0.1014)	(0.057)

Source: IMF staff compilation.
Note: All specifications include exporter-by-year and importer-by-year fixed effects. Standard errors are shown in parenthesis and clustered at the importing country level. *, **, and *** indicate coefficients are statistically different from 0 at the 10%, 5%, and 1% levels, respectively.

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[3] Because most of those variables do not vary over time, a static version of the gravity equation is also estimated for each year. There is no clear trend in the coefficients on geopolitical distance estimated in that manner.

[4] The inverse hyperbolic sine is defined as $y_{cijt} = \log\left(v_{cijt} + \sqrt{1 + v_{cijt}^2}\right)$, where v_{cijt} is the value of trade. This function is well defined at $v_{cijt} = 0$, but quickly converges to $\log(2 \times v_{cijt})$ as v_{cijt} grows. The coefficients α_c can thus be interpreted as elasticities when there is trade.

Online Annex 3.4. A Multi-country, Partial Equilibrium Commodity Market Model

Based on Alvarez and others (2023), we consider a single-commodity model with multiple countries that face country-specific supply (s) and demand (d) curves of the following form:

$$\ln\left(q_c^s\right) = \eta^s \ln(p_c) + \gamma_c^s$$
$$\ln\left(q_c^d\right) = \eta^d \ln(p_c) + \gamma_c^d \,,$$

where *c* denotes the country, q_c^s and q_c^d are quantities supplied and demanded, p_c is the commodity price, and $\eta^s > 0$ and $\eta^d < 0$ are the price elasticities of supply and demand of the commodity. For simplicity, all countries are assumed to have the same supply and demand elasticities, but have unique demand and supply shifters, γ_c^s and γ_c^d.

Countries are in one of two blocs $B\epsilon\{USA - Europe+, China - Russia +\}$. Aggregating all countries within a single bloc B, we get the following bloc-level demand and supply curves.

$$\ln\left(Q_B^s\right) = \eta^s \ln\left(p_B\right) + \gamma_B^s$$
$$\ln\left(Q_B^d\right) = \eta^d \ln\left(p_B\right) + \gamma_B^d$$

where $Q_B^s = \sum_{c\epsilon B} q_c^s \,, Q_B^d = \sum_{c\epsilon B} q_c^d \,, \gamma_B^s = \log\left(\sum_{c\epsilon B} e^{\gamma_c^s}\right)$ and $\gamma_B^d = \log\left(\sum_{c\epsilon B} e^{\gamma_c^d}\right)$. This defines two market equilibria: One that allows for trade between blocs and one that does not.

Integrated market equilibrium. The integrated market equilibrium must fulfill market clearing and non-arbitrage conditions such that $Q_{USA-EU+}^s + Q_{CHN-RUS+}^s = Q_{USA-EU+}^d + Q_{CHN-RUS+}^d$ and $p_{USA-EU+} = p_{CHN-RUS+} = p_w$, where p_w is the world price. The equilibrium world price can then be written as a function of supply and demand parameters. That is,

$$\ln(\mathrm{p_w}) = \frac{1}{\eta^s - \eta^d} * \left(\Omega^\mathrm{d} - \Omega^\mathrm{s}\right),$$

where $\Omega^\mathrm{d} \equiv \ln(e^{\gamma_{USA-EU+}^d} + e^{\gamma_{CHN-RUS+}^d})$ and $\Omega^\mathrm{s} \equiv \ln(e^{\gamma_{USA-EU+}^s} + e^{\gamma_{CHN-RUS+}^s})$. The equilibrium world price can be substituted into bloc- or country-specific demand and supply curves to obtain the corresponding quantities demanded, supplied, and net exports/imports.

Fragmented market equilibrium. The fragmented market equilibrium assumes no trade between blocs, while trading costs within a bloc are zero. The equilibrium prices and quantities must then fulfill bloc-level market clearing conditions. The new market equilibrium prices in a bloc *B* is

$$\ln\left(p_B\right) = \frac{\left(\gamma_B^d - \gamma_B^s\right)}{\eta^s - \eta^d}$$

Bloc- and country-level quantities and net exports can be obtained by substituting bloc level prices, p_B, into the corresponding supply and demand curves.

Fragmentation impact. In the model, the impact of fragmentation is the difference in country- or bloc-level quantities and prices between the fragmented and integrated market equilibria. The change in price is given by:

$$\ln(p_B) - \ln(\mathrm{p_W}) = \frac{1}{\eta^s - \eta^d} * [(\gamma_B^d - \gamma_B^s) - (\Omega^\mathrm{d} - \Omega^\mathrm{s})]$$

In our calibration, $\mathrm{p_W}$ is standardized to 1, so that

$$\gamma_c^d = \ln(q_c^d) = observed\ initial\ quantity\ demanded$$

$$\gamma_c^s = \ln(q_c^s) = observed\ initial\ quantity\ supplied$$

From initial equilibrium conditions, $\Omega^\mathrm{d} = \ln(e^{\gamma_{USA-EU+}^d} + e^{\gamma_{CHN-RUS+}^d}) = \ln(q_{USA-EU+}^d + q_{CHN-RUS+}^d) = \Omega^\mathrm{s}$, so $\Omega^\mathrm{d} - \Omega^\mathrm{s} = 0$. The effect of fragmentation on prices is given by:

$$\ln(p_B) - \ln(\mathrm{p_w}) = \frac{\gamma_B^d - \gamma_B^s}{\eta^s - \eta^d}$$

Consumer, producer and total surplus changes. The simple model can be used to analyze changes in producer and consumer surplus. These are calculated as the change in areas under the demand curve (above equilibrium prices), for consumer surplus changes, and the change in the areas above the supply curve (under equilibrium prices), for producer surplus changes. More specifically, changes in consumer and producer surplus for country c are given by:

$$\Delta \mathrm{CS_c} = -\int_{p_w}^{p_c} e^{\eta^d \ln(p\ \ ) + \gamma^d} dp = -p_w q_{c,w}^d \frac{\left(\frac{p_c}{p_w}\right)^{1+\eta^d} - 1}{\eta^d + 1}$$

$$\Delta \mathrm{PS_c} = \int_{p_w}^{p_c} e^{\eta^s \ln(p\ \ ) + \gamma^s} dp = p_w q_{c,w}^s \frac{\left(\frac{p_c}{p_w}\right)^{1+\eta^s} - 1}{\eta^s + 1}$$

where $p_c = \mathrm{p_B}$, is the price faced by country *c* (which equals the bloc-level price in the fragmented equilibrium), and $p_w q_{c,w}^d$ and $p_w q_{c,w}^s$ are the quantities, in dollars, demanded and supplied in the integrated market equilibrium. Surplus changes are larger in countries that experience a larger price change in a largely consumed or produced commodity. Total surplus is the sum of consumer and producer surplus in a particular economy.

Calibration of the model

The model is calibrated so that the pre-fragmentation economy matches observed country and bloc-level trade flows for 2019, prior to the onset of the COVID-19 pandemic.[5]

Demand and supply shifters (γ_c^d, γ_c^s)

Standardizing the integrated market price to one ($\mathrm{p_W} = 1$), γ_c^d and γ_c^s are calibrated to match the log of the initial quantity demanded and supplied of a particular commodity. The quantity

[5] Due to data quality considerations, the calibration of crude oil and zirconium uses data from 2018.

produced is the volume in metric tons of content of a commodity. The quantity demanded is calibrated as the quantity produced minus net exports volume for each commodity.[6]

Elasticity parameters (η^d, η^s)

The calibration of elasticity parameters is informed by empirical estimates from the literature, as documented in the surveys by Fally and Sayre (2018) and Dahl (2020). The calibration of η^d and η^s, namely the demand and supply elasticities, is as follows: For energy and agricultural commodities, we use the average of the minimum and maximum short-run price elasticities in the literature review in Fally and Sayre (2018). For mineral commodities, we use the median of the short-run elasticities in the minerals-focused literature review by Dahl (2020). If no estimate of a particular commodity is available, we use the average elasticity for the type of commodity (e.g., agriculture and minerals). Details on the elasticities used for each commodity and their sources can be found in Alvarez and others (2023).

Online Annex 3.5. Partial Equilibrium Model: Additional Results

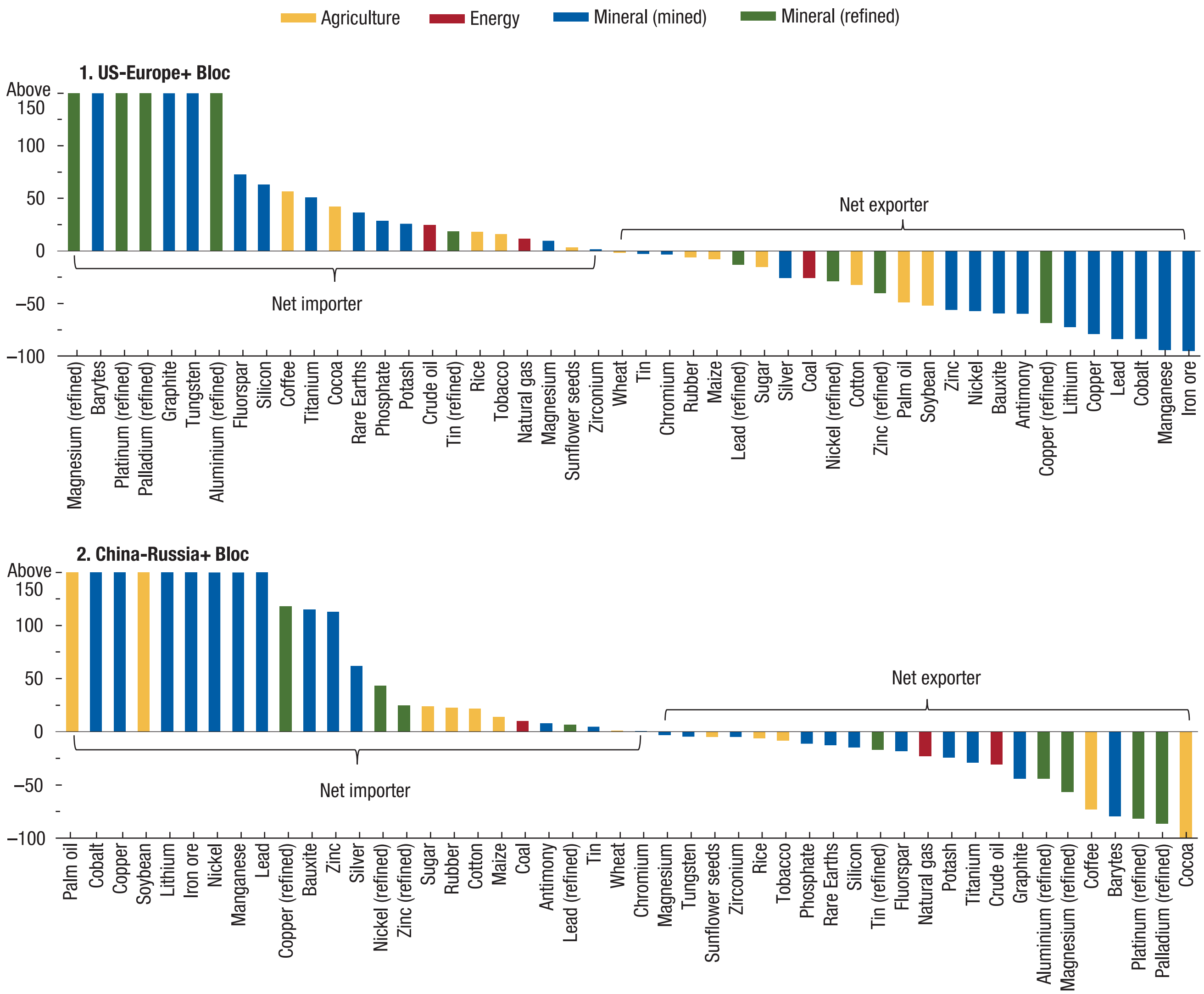
This section presents additional results from the single-commodity partial equilibrium model. It draws on Alvarez and others (2023).

3.5.1. Baseline Specification: Additional Results

This subsection provides additional commodity-specific results for the baseline scenario. Annex Figure 3.5.1. presents the fragmentation-induced changes in prices in the baseline scenario for each commodity in the two blocs. Annex Figure 3.5.2. elaborates on the price effects from individual countries switching blocs. For each bloc, it shows the 15 largest price increases that would be induced by an exporter switching trade allegiances. Annex Figure 3.5.3. highlights the 5 commodities that generate the largest drops in total bloc-level surplus in each bloc. Finally, Annex Figure 3.5.4. plots the distribution of the country-level changes in total surplus from fragmentation across countries and commodities.

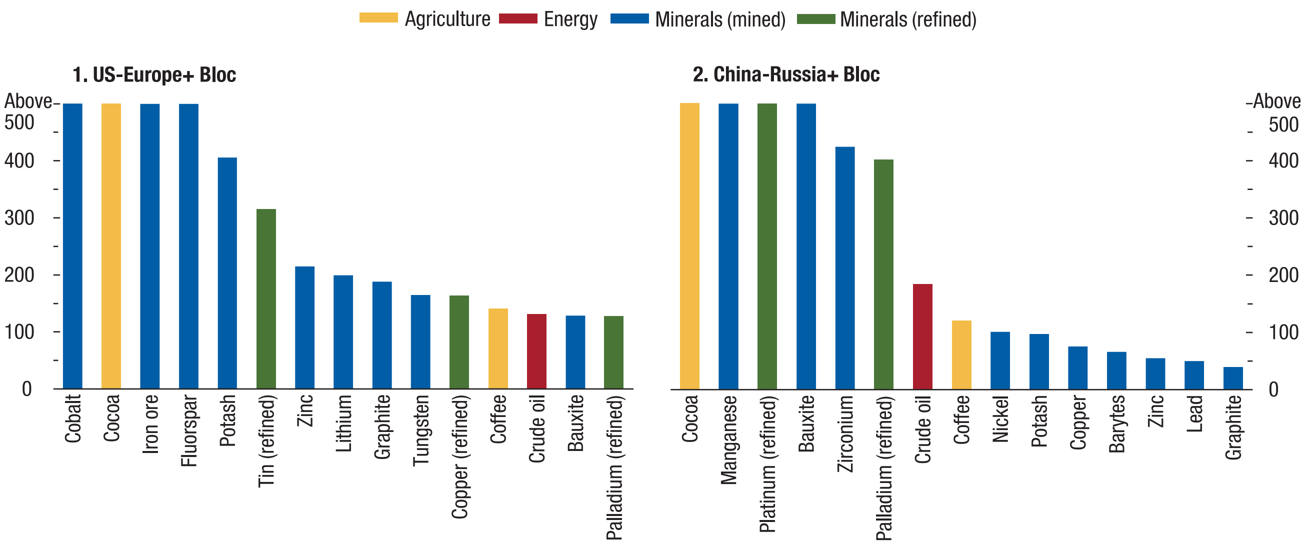
[6] For consistency, whenever a country has positive values for the quantity produced of a given commodity and net exports are greater than production, production is set equal to net exports.

Online Annex Figure 3.5.1. Price Changes Due to Fragmentation in Individual Commodity Markets
(Percent)



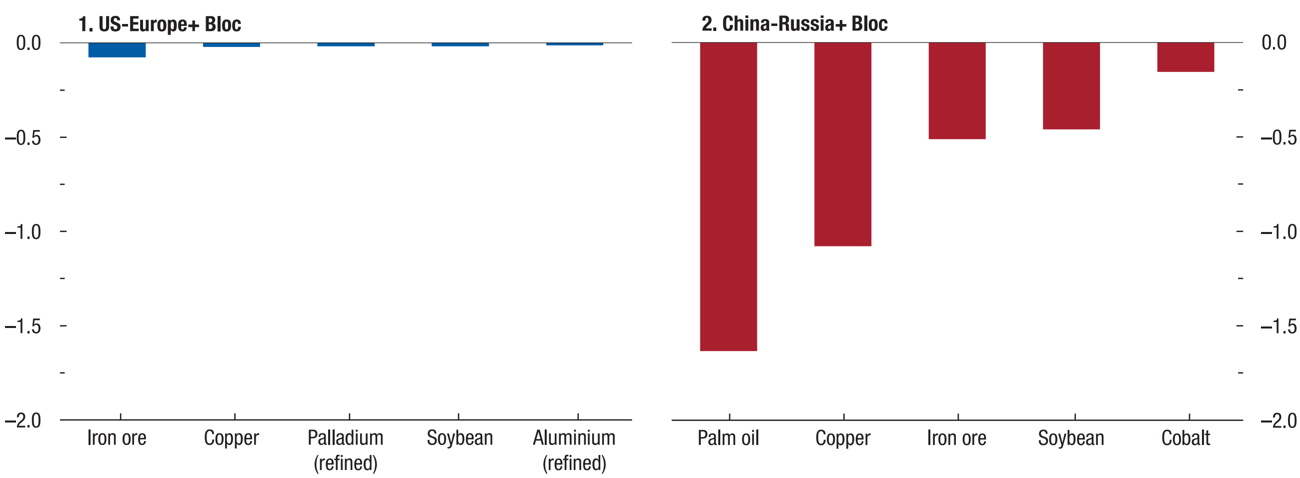
Sources: British Geological Survey; Dahl (2020); Fally and Sayre (2018); Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.
Note: Each bar represents the commodity price change in each bloc induced by fragmentation of trade in the specific commodity. Price effects are capped at 150 percent for ease of exposition.

Online Annex Figure 3.5.2. Top 15 Largest Price Increases from a Single Exporter Switching Blocs
(Percent)



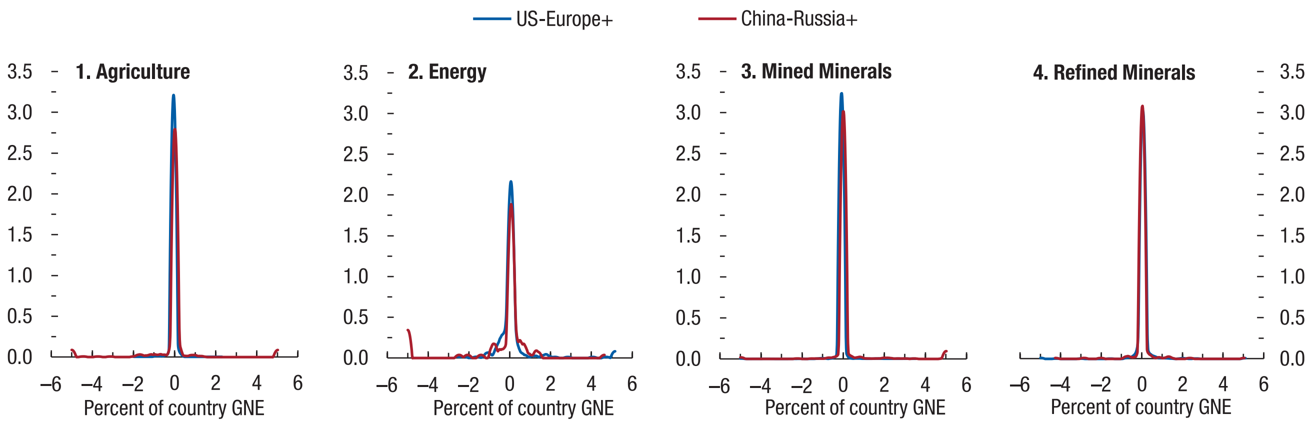
Sources: British Geological Survey; Dahl (2020); Fally and Sayre (2018); Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.
Note: Each bar represents the largest bloc-level price increase that the corresponding commodity experiences from a single exporting country switching to the other bloc.

Online Annex Figure 3.5.3. Top Five Largest Changes in Bloc-Level Total Economic Surplus
(Percent of bloc-level GNE)



Sources: British Geological Survey; Dahl (2020); Fally and Sayre (2018); Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.
Note: Each bar represents the decline in bloc-level total economic surplus from fragmenting trade of the corresponding commodity in the axis. GNE = gross national expenditure.

Online Annex Figure 3.5.4. Distribution of Country-Level Changes in Total Surplus Due to Fragmentation in Individual Commodity Markets
(Density)



Sources: British Geological Survey; Dahl (2020), Fally and Sayre (2018); Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.
Note: Changes in total economic surplus at the country level are capped at +/– 5 percent of GNE for readability. Each observation represents the total economic change in the surplus of a country due to the fragmentation of a single commodity market. The *y*-axis is the probability density function for the kernel density estimation. GNE = gross national expenditure.

3.5.2. Alternative Bloc Configurations

This subsection discusses the implications on price and total economic surplus changes across the two blocs due to trade fragmentation under different bloc configurations (see Table 3.5.1. for the alternative bloc configurations considered). We examine two alternatives to the baseline. In bloc configuration A, like Chapter 4 of the April 2023 World Economic Outlook, all emerging and developing economies, excluding India, Indonesia and Latin American countries, are assigned to the China-Russia+ bloc. In bloc configuration B, a country is assigned to the US-Europe+ bloc if it trades more with the US and the EU combined than with China and Russia combined. A country is assigned to the China-Russia+ bloc if it trades more with China and Russia combined than with the US and EU combined.[7,8]

[7] Trade shares are calculated using 2019 data from UN Comtrade.
[8] Note that the single-commodity partial equilibrium exercise cannot accommodate bloc configurations in which some countries remain neutral, as was instead done in Chapter 4 of the April 2023 World Economic Outlook chapter.

Online Annex Table 3.5.1. Alternative Bloc Configurations

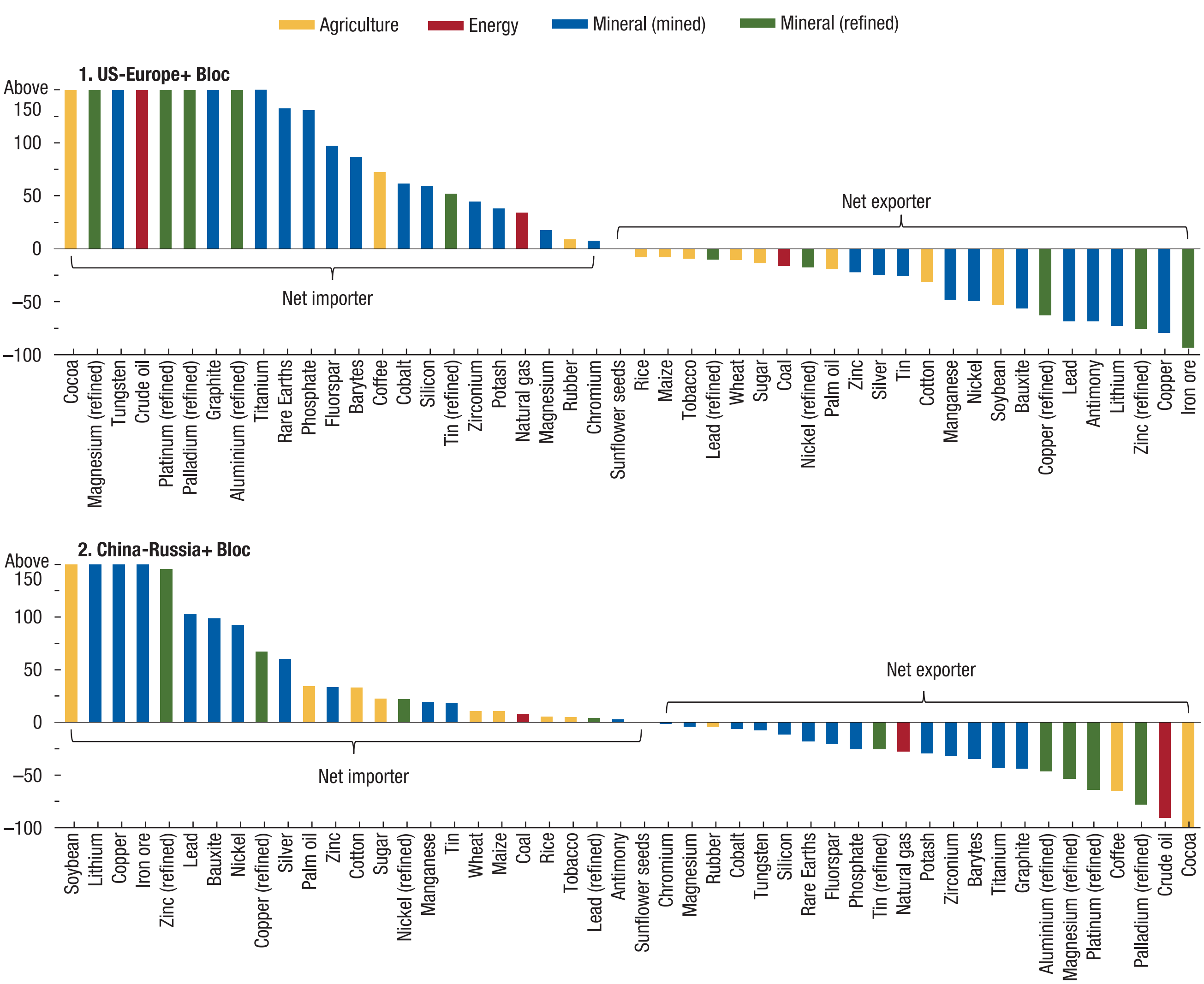
	US-Europe+ bloc	China-Russia+ bloc
Bloc configuration A	Andorra; Argentina; Aruba; Australia; Austria; Belgium; Brazil; Bulgaria; Canada; Chile; Colombia; Costa Rica; Croatia; Cyprus; Czech Republic; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Iceland; India; Indonesia; Ireland; Israel; Italy; Japan; Korea; Latvia; Lithuania; Luxembourg; Malta; Mexico; Netherlands; New Zealand; Norway; Peru; Poland; Portugal; Puerto Rico; Romania; Serbia; Slovak Republic; Slovenia; Spain; Sweden; Switzerland; Tuvalu; United Kingdom; United States	Afghanistan; Albania; Algeria; Angola; Antigua and Barbuda; Armenia; Azerbaijan; Bahamas, The; Bahrain; Bangladesh; Barbados; Belarus; Belize; Benin; Bhutan; Bolivia; Bosnia and Herzegovina; Botswana; Brunei Darussalam; Burkina Faso; Burundi; Cabo Verde; Cambodia; Cameroon; Central African Republic; Chad; China; Comoros; Congo, Democratic Republic of the; Congo, Republic of; Côte d'Ivoire; Djibouti; Dominica; Dominican Republic; Ecuador; Egypt; El Salvador; Equatorial Guinea; Eritrea; Eswatini; Ethiopia; Fiji; Gabon; Gambia, The; Georgia; Ghana; Grenada; Guatemala; Guinea; Guinea-Bissau; Guyana; Haiti; Honduras; Hong Kong SAR; Iran; Iraq; Jamaica; Jordan; Kazakhstan; Kenya; Kiribati; Kosovo; Kuwait; Kyrgyz Republic; Lao P.D.R.; Lebanon; Lesotho; Liberia; Libya; Macao SAR; Madagascar; Malawi; Malaysia; Maldives; Mali; Marshall Islands; Mauritania; Mauritius; Micronesia; Moldova; Mongolia; Montenegro, Rep. of; Morocco; Mozambique; Myanmar; Namibia; Nauru; Nepal; Nicaragua; Niger; Nigeria; North Macedonia; Oman; Pakistan; Palau; Panama; Papua New Guinea; Paraguay; Philippines; Qatar; Russia; Rwanda; Samoa; San Marino; São Tomé and Príncipe; Saudi Arabia; Senegal; Seychelles; Sierra Leone; Singapore; Solomon Islands; Somalia; South Africa; South Sudan; Sri Lanka; St. Kitts and Nevis; St. Lucia; St. Vincent and the Grenadines; Sudan; Suriname; Syria; Tajikistan; Tanzania; Thailand; Timor-Leste; Togo; Tonga; Trinidad and Tobago; Tunisia; Türkiye; Turkmenistan; Uganda; Ukraine; United Arab Emirates; Uruguay; Uzbekistan; Vanuatu; Venezuela; Vietnam; Yemen; Zambia; Zimbabwe
Bloc configuration B (main trading partner)	Albania; Algeria; Andorra; Antigua and Barbuda; Argentina; Aruba; Austria; Azerbaijan; Bahamas, The; Bahrain; Bangladesh; Barbados; Belgium; Belize; Bhutan; Bolivia; Bosnia and Herzegovina; Botswana; Brazil; Bulgaria; Burkina Faso; Burundi; Cabo Verde; Cambodia; Cameroon; Canada; Central African Republic; Chile; Colombia; Comoros; Costa Rica; Côte d'Ivoire; Croatia; Cyprus; Czech Republic; Denmark; Dominica; Dominican Republic; Ecuador; Egypt; El Salvador; Equatorial Guinea; Estonia; Eswatini; Ethiopia; Fiji; Finland; France; Georgia; Germany; Greece; Grenada; Guatemala; Guinea-Bissau; Guyana; Haiti; Honduras; Hungary; Iceland; India; Ireland; Israel; Italy; Jamaica; Japan; Jordan; Kosovo; Latvia; Lebanon; Lesotho; Libya; Lithuania; Luxembourg; Madagascar; Mali; Malta; Mauritius; Mexico; Micronesia; Moldova; Montenegro, Rep. of; Morocco; Mozambique; Namibia; Nauru; Netherlands; Nicaragua; Niger; Nigeria; North Macedonia; Norway; Pakistan; Palau; Panama; Paraguay; Peru; Poland; Portugal; Puerto Rico; Qatar; Romania; San Marino; São Tomé and Príncipe; Saudi Arabia; Senegal; Serbia; Seychelles; Sierra Leone; Slovak Republic; Slovenia; South Africa; Spain; Sri Lanka; St. Kitts and Nevis; St. Lucia; St. Vincent and the Grenadines; Suriname; Sweden; Switzerland; Trinidad and Tobago; Tunisia; Türkiye; Uganda; Ukraine; United Arab Emirates; United Kingdom; United States; Venezuela	Afghanistan; Angola; Armenia; Australia; Belarus; Benin; Brunei Darussalam; Chad; China; Congo, Democratic Republic of the; Congo, Republic of; Djibouti; Eritrea; Gabon; Gambia, The; Ghana; Guinea; Hong Kong SAR; Indonesia; Iran; Iraq; Kazakhstan; Kenya; Kiribati; Korea; Kuwait; Kyrgyz Republic; Lao P.D.R.; Liberia; Macao SAR; Malawi; Malaysia; Maldives; Marshall Islands; Mauritania; Mongolia; Myanmar; Nepal; New Zealand; Oman; Papua New Guinea; Philippines; Russia; Rwanda; Samoa; Singapore; Solomon Islands; Somalia; South Sudan; Sudan; Syria; Tajikistan; Tanzania; Thailand; Timor-Leste; Togo; Tonga; Turkmenistan; Tuvalu; Uruguay; Uzbekistan; Vanuatu; Vietnam; Yemen; Zambia; Zimbabwe

Sources: UN Comtrade data; and IMF staff compilation.

Bloc configuration A

This configuration leads to price increases for a larger number of commodities in the US-Europe+ bloc than under the baseline. Key differences relative to the baseline are as follows: (1) The price of crude oil increases by more in the US-Europe+ bloc as major oil producers are now in the China-Russia+ bloc (UAE, Libya, Nigeria, Qatar, Saudi Arabia, Kuwait); (2) the price of cocoa increases in the US-Europe+ bloc, as Ivory Coast, the largest world producer of cocoa, becomes part of the China-Russia+ bloc; (3) the Democratic Republic of Congo, the world largest producer of cobalt, has been moved to the China-Russia bloc, leading to a rise in the price of cobalt in the US-Europe+ bloc; (4) the China-Russia bloc experiences milder price increases for palm oil and manganese. The former is because important palm oil producers such as Malaysia and Thailand are now assigned to the China-Russia+ bloc. Manganese becomes less

Online Annex Figure 3.5.5. Price Changes from Trade Fragmentation by Commodity under Bloc Configuration A
(Percent)

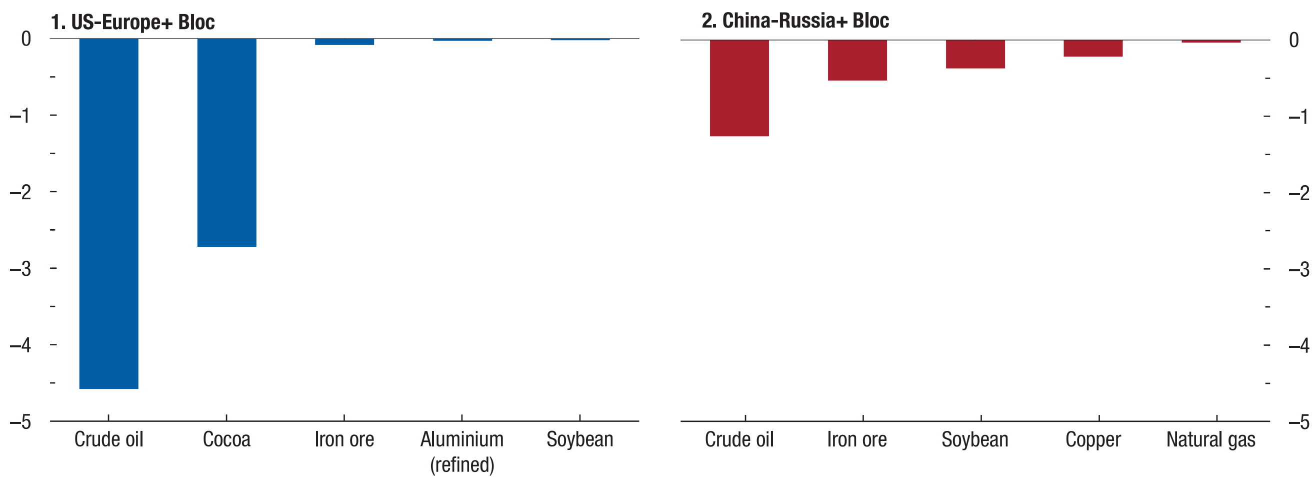


Sources: British Geological Survey; Dahl (2020); Fally and Sayre (2018); Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.
Note: Each bar represents the commodity price change in each bloc induced by fragmentation of trade in the specific commodity. Price effects are capped at 150 percent for ease of exposition.

vulnerable in the China-Russia+ bloc because India, a major importer of this commodity, is now assigned to the US-Europe+ bloc.

Turning to the implications of fragmentation for changes in total surplus across blocs, crude oil and cocoa are now the commodities causing the largest surplus declines in the US-Europe+ blocs. They imply surplus losses in the US-Europe+ bloc between 2.5 and 4.5 percent of GNE. This is because both commodities experience large price increases, while also being widely used as inputs in the economy. Crude oil is also causing relevant surplus declines in the China-Russia bloc (over 1 percent of GNE). In this case, it is due to producers surplus declining, as exporting countries in this bloc experience large reduction in prices.

Online Annex Figure 3.5.6. Top Five Largest Changes in Bloc-Level Total Economic Surplus under Bloc Configuration A
(Percent of bloc-level GNE)



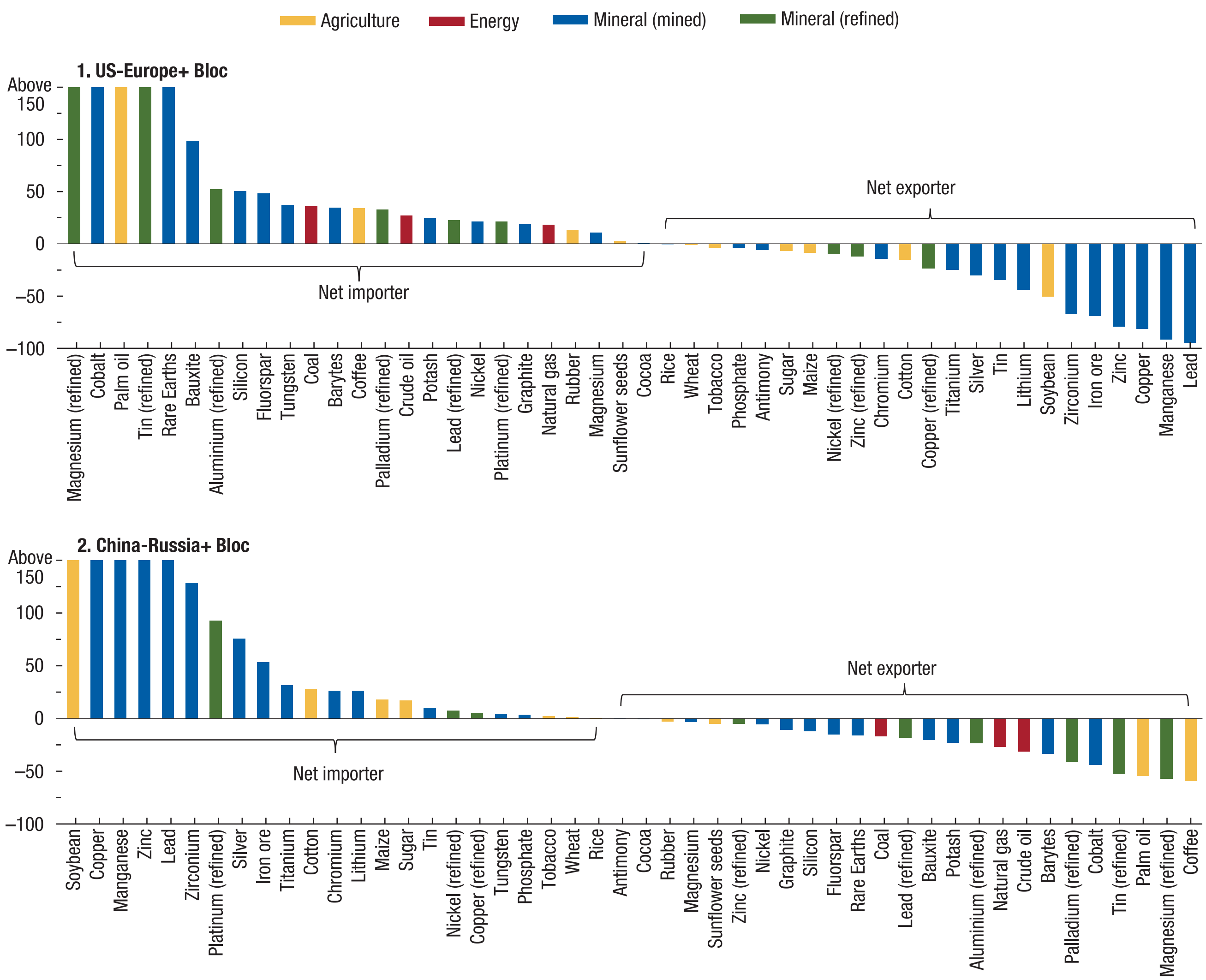
Sources: British Geological Survey; Dahl (2020); Fally and Sayre (2018); Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.
Note: Each bar represents the decline in bloc -level total economic surplus from fragmenting trade of the corresponding commodity in the axis. GNE = gross national expenditure.

Bloc configuration B (major trade partner)

Relative to the baseline specification, the major changes are represented by the assignment of India, Mozambique, South Africa to the US-Europe+ bloc, and of Australia, the Democratic Republic of the Congo, Indonesia, Korea, Malaysia, New Zealand, Philippines, and Thailand to the China-Russia+ bloc. Under this specification, the US-Europe+ bloc experiences large price increases in palm oil (given the shift of Indonesia and Malaysia, which account for 80 percent of global production) and cobalt (given the shift of the DRC), but is less vulnerable to trade fragmentation of graphite, refined platinum, and refined palladium (given that Mozambique and South Africa are now in the US-Europe+ bloc). Like in the baseline, the China-Russia bloc still experiences large price increases of soybean, copper, manganese, zinc, and lead, but not of iron ore and lithium (given the assignment of Australia to the China-Russia+ bloc), or of palm oil

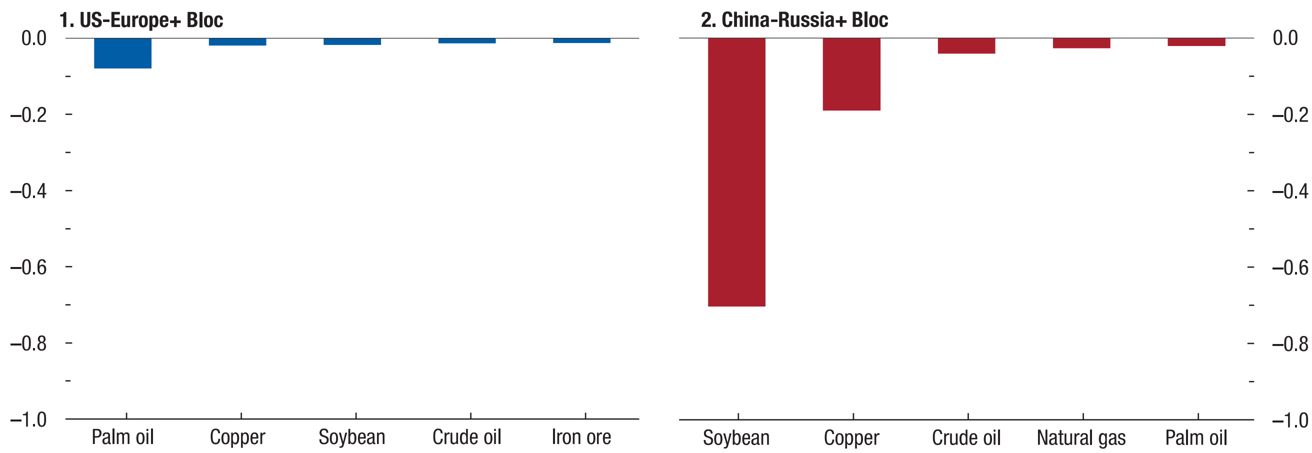
(Figure 3.5.7). Changes in total economic surplus are larger in the China-Russia+ bloc (Figure 3.5.8), but lower in magnitude relative to the baseline.

Online Annex Figure 3.5.7. Price Changes from Trade Fragmentation by Commodity under Bloc Configuration B
(Percent)



Sources: British Geological Survey; Dahl (2020); Fally and Sayre (2018); Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.
Note: Each bar represents the commodity price change in each bloc induced by fragmentation of trade in the specific commodity. Price effects are capped at 150 percent for ease of exposition.

Online Annex Figure 3.5.8. Top Five Largest Changes in Bloc-Level Total Economic Surplus under Bloc Configuration B
(Percent of bloc-level GNE)



Sources: British Geological Survey; Dahl (2020); Fally and Sayre (2018); Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.
Note: Each bar represents the decline in bloc-level total economic surplus from fragmenting trade of the corresponding commodity in the axis. GNE = gross national expenditure.

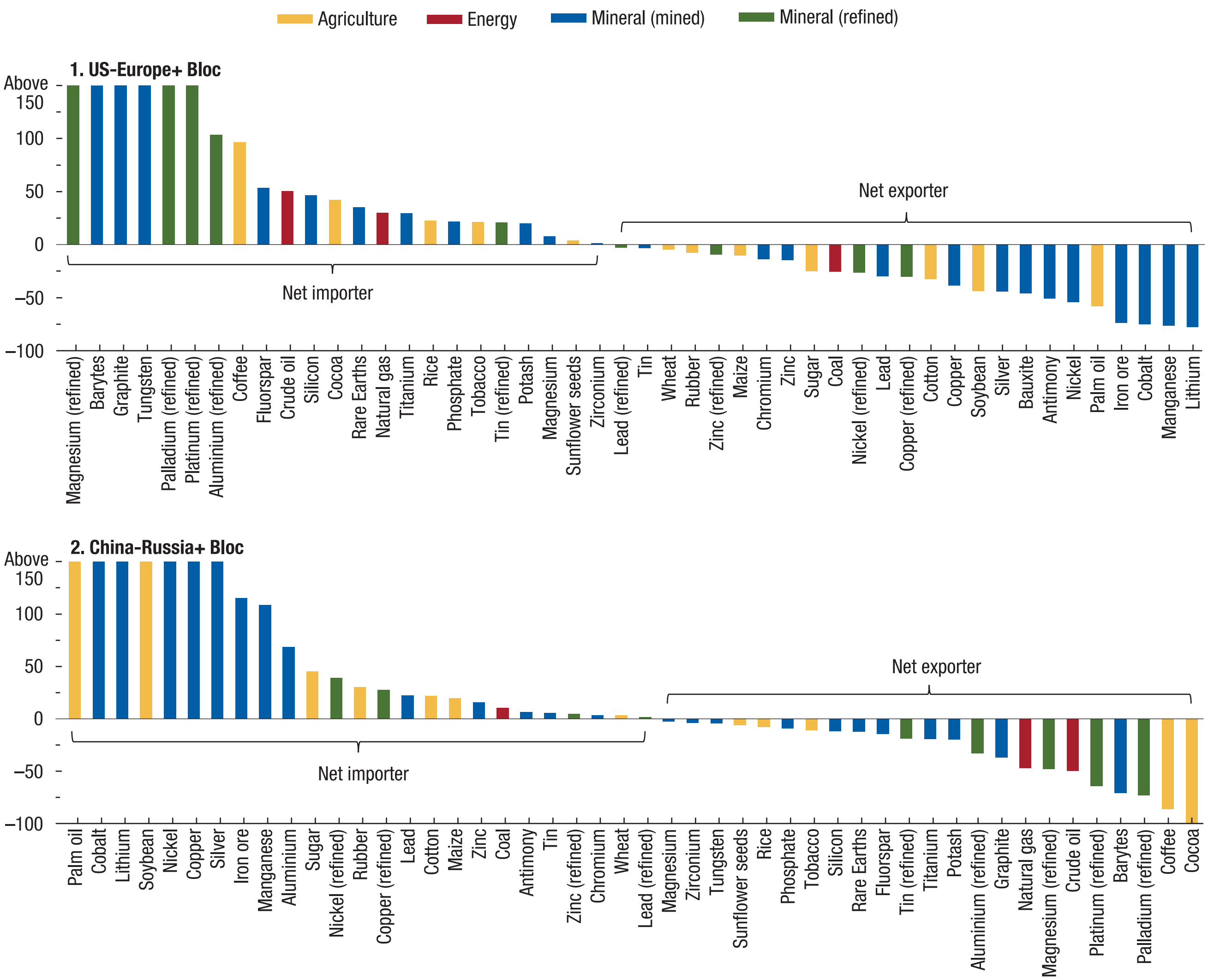
3.5.3. Alternative Elasticities

This subsection shows the sensitivity of the results to different elasticities (for the alternative elasticities considered see Alvarez and others, 2023). Under this alternative specification the demand and supply elasticities are set as the median values among the estimates listed in the literature review in Fally and Sayre (2018). Missing information on the supply and demand elasticities of a commodity are replaced with the average elasticity by broader categories.

As shown in Figure 3.5.9, the ranking of commodity price vulnerability to fragmentation is overall in line with the baseline (illustrated in Figure 3.5.1). The results on the five largest surplus changes across blocs in Figure 3.5.10 are also broadly in line the baseline (in Figure 3.5.2).

Online Annex Figure 3.5.9. Price Changes from Trade Fragmentation by Commodity under an Alternative Elasticities Configuration

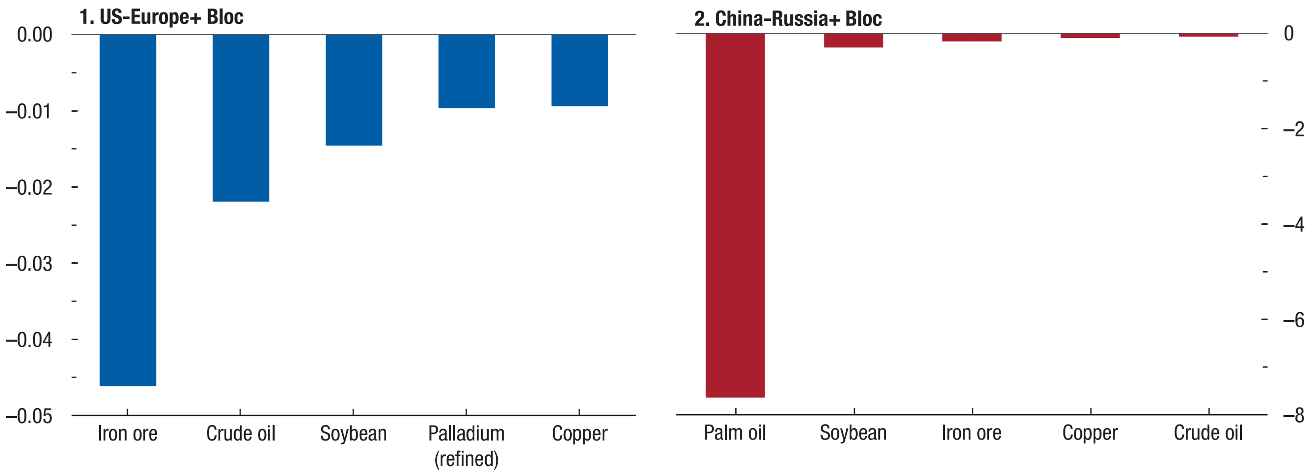
(Percent)



Sources: British Geological Survey; Dahl (2020); Fally and Sayre (2018); Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.

Note: Each bar represents the commodity price change in each bloc induced by fragmentation of trade in the specific commodity. Price effects are capped at 150 percent for ease of exposition.

Online Annex Figure 3.5.10. Top Five Largest Changes in Bloc-Level Total Economic Surplus under an Alternative Elasticities Configuration
(Percent of bloc-level GNE)



Sources: British Geological Survey; Dahl (2020); Fally and Sayre (2018); Food and Agriculture Organization of the United Nations; Gaulier and Zignano (2010); International Energy Agency; US Geological Survey; and IMF staff calculations.
Note: Each bar represents the decline in bloc -level total economic surplus from fragmenting trade of the corresponding commodity in the axis. GNE = gross national expenditure.

Online Annex 3.6. GMMET Model

This section provides details on the Global Macroeconomic Model for Energy Transition (GMMET), the extensions implemented for the chapter, data sources, and simulations.

3.6.1. Description of GMMET

GMMET is a general equilibrium multi-region multi-sector model configured here for six regions. The regional specification is designed to restrict trade between two hypothetical blocs, the US-Europe+ bloc and the China-Russia+ bloc as described in Online Annex Table 3.1.1. The six regions are: The US; the EU; a region comprising countries leaning toward the US and the EU; China; Russia; and a region comprising countries leaning toward China and Russia. The model belongs to the class of large-scale structural New-Keynesian dynamic general equilibrium models that are traditionally used for the quantitative short- and medium-term analysis of monetary and fiscal policy. Its core macroeconomic structure is described in Carton and others (2023) and Kumhof and others (2010).

The Core Structure

Each period corresponds to a calendar year. The model features liquidity-constrained households, who consume all income each period, and overlapping-generations households, who decide how much to consume and save and how much to work. Households consume standard goods and services, energy for residential purposes (natural gas and electricity) and transportation services. Transportation services are provided with conventional cars burning gasoline (that comes from oil) and electric vehicles (EVs) running on electricity. The choice of whether to purchase a conventional car or an EV depends on their relative prices.

Both types of households exhibit non-Ricardian behavior, which allows fiscal policy to have an impact on macroeconomic variables even in the long run (Blanchard, 1985). Firms in non-energy sectors produce tradable and nontradable goods based on energy inputs (from fossil fuel and renewable sources) and labor and capital.

In each region, there are governments and central banks, which follow specific budgetary and monetary rules. As in standard New-Keynesian models, nominal and real rigidities in domestic production, labor market and trade make monetary and fiscal policy have notable near-to-medium-term effects.

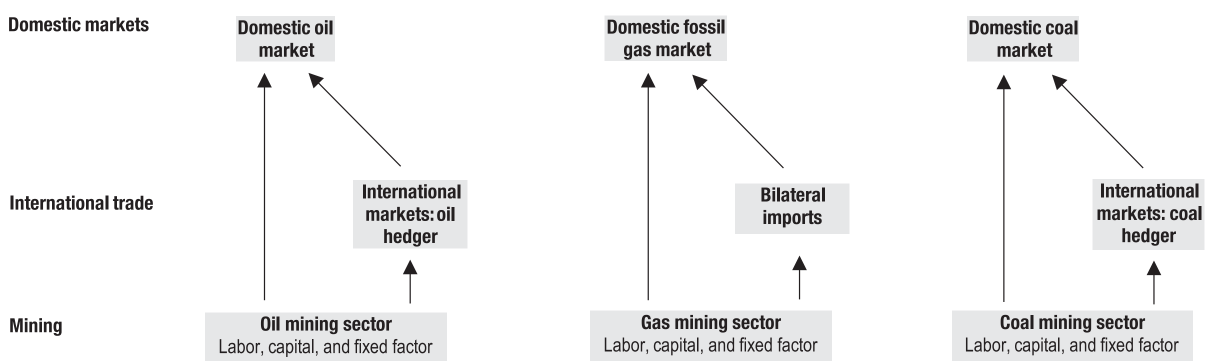
In the model, all markets clear in each period at the equilibrium prices and the prices for all good and services are reflected in CPI indexes in each region.

Fossil Fuel Energy Sectors

Energy production originates from three fossil fuel mining sectors – coal, gas, and crude oil – each combining capital and labor with a resource, which is fixed in each period, but scalable over time, accounting for limited possibilities to adjust mining capacity in the short run (coal mines, gas or oil wells). All three fuels are sold to the tradable sector as an intermediate input. Oil and gas are also consumed by households (as car gasoline and fuel for home heating, respectively); natural gas and coal are also sold as fuel for electricity generation.

There are domestic and international markets for oil. The model extends Carton and others (2023) by allowing for international trade of oil in perfectly integrated markets as well as in segmented markets as detailed in Online Annex Figure 3.6.1.

Online Annex Figure 3.6.1. Fossil Fuels Markets



Source: IMF staff compilation.

There is a hedger that aggregates oil exports from producing regions and sells to importing region according to their demand. In the absence of restrictions, markets are perfectly integrated, and the hedger sets commodity prices such that markets clear at the global level. In case of restrictions of trade across blocs, the hedger sets prices in each bloc such that the market clears at the single bloc market level.

Coal markets operate in a similar fashion. Natural gas markets, however, are structured differently. Segmentation in gas markets arises from the need of pipelines and other structures (e.g., LNG terminals) for transportation. Thus, international trade of natural gas is modelled as a bilateral flow between regions.

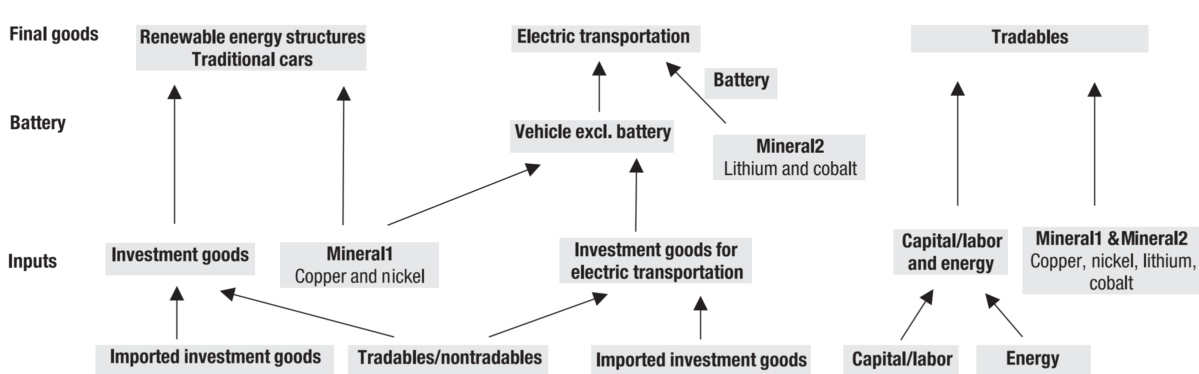
Minerals Sector

Relative to the GMMET in Carton and others (2023), the model is augmented with minerals sectors key for the green energy transition: Copper, nickel, lithium, and cobalt. Copper, which is used in cables and conductors, is essential for the turbines and panels in solar and wind electricity generation (renewables). Nickel is used in the bearings, shafts, gears, and hydraulic components of wind turbines. Lithium and cobalt form an essential part of the lithium-ion batteries used in EVs.

Minerals enter the model in two mineral composites sectors; copper and nickel (*mineral1*); and lithium and cobalt (*mineral2*). Besides being crucial inputs for the green transition, the mineral composites are used in other production processes, such as for manufacturing goods and building structures, combined in a unique tradables bundle, and for conventional cars (CC). The use of minerals in the production of tradables and CC represents another extension of GMMET relative to Carton and others (2023).

To produce CCs and EVs, *mineral1* is combined with an investment good to construct the bulk of the vehicle (Online Annex Figure 3.6.2.). Additionally, for EVs, *mineral2* is added, as a proxy for the battery component at a second stage. Investment goods are either produced with a bundle of domestically produced tradables and non-tradables or entirely imported. Structures for renewable energy (solar panels, wind turbines) are produced with a technology that resembles the one for CCs using a bundle of investment goods and *mineral1*. EVs are produced in each region and are bundled and traded together with other final products. Finally, to produce tradable goods, the model combines *mineral1* and *mineral2* with a capital/labor and energy bundle. As shown in Online Annex Figure 3.6.2., availability of minerals affects the production of solar panels, wind turbines and cars either directly or indirectly, through the tradables inputs.

Online Annex Figure 3.6.2. Use of Minerals



Source: IMF staff compilation.

The model focuses on minerals at the mining stage, as the geographical location of endowments is important for the impact of fragmentation. Mining of the two mineral composites is structured in the same way – each combining capital and labor with a resource, which is fixed in each period. Minerals can be traded in integrated international market as well as in segmented markets, following the same structure of oil and coal (Online Annex Figure 3.6.1).

Data and Parameter Specification

Production technologies in the model are CES and feature constant return to scale. The calibrated model reproduces empirical estimates of the supply elasticity of fossil fuel commodities and the four critical minerals (Fally and Sayre, 2018; Dahl, 2020). The production and trade intensities of fossil fuels commodities and minerals are calibrated using the BGS, US Geological Survey, Bilateral Commodity Trade Database, IEA, and Eurostat.

Online Annex Table 3.6.1. Mineral Use, Supply and Trade
(Percent of region GDP, unless noted otherwise)

	United States	European Union	Countries learning toward USA-Europe+	China	Russia	Countries leaning toward China-Russia+
	(1)	(2)	(3)	(4)	(5)	(6)
GDP (percent of world)	24.60	18.10	27.60	16.50	1.80	11.40
Mineral1 (copper and nickel)	0.03	0.07	0.28	0.41	0.61	0.10
Production	0.04	0.04	0.48	0.08	0.53	0.16
Net imports	–0.01	0.03	–0.19	0.33	0.07	–0.06
Mineral2 (lithium and cobalt)	0.00	0.01	0.01	0.03	0.02	0.01
Production	0.00	0.00	0.03	0.00	0.01	0.00
Net imports	0.00	0.01	–0.02	0.03	0.01	0.00

Sources: British geological survey; Gaulier and Zignano (2010); Global macroecomic model for the energy transition; and IMF staff calculations.
Note: Accounting errors due to rounding. Minerals data are at the mined stage.

All key parameters, including for the fossil fuel sectors, are in line with Carton and others (2023). Online Annex Table 3.6.1 focuses on the calibration of the mineral sector. The extraction and use of *mineral1* and *mineral2* are based primarily on 2018 and 2019 data.[9] Online Annex Table 3.6.2. outlines the key values in the benchmark calibration for the use of minerals as well as alternative calibrations. Generally, both *mineral1* and *mineral2* cannot easily be substituted by other minerals or intermediate goods (Fally and Sayre, 2018; Dahl, 2020). Further, the use of *mineral1* in the production of renewables is also assumed to be inelastic, with an

Online Annex Table 3.6.2. Minerals' Elasticities of Substitution

	Benchmark	Higher
	(1)	(2)
Elasticity between:		
Minerals and other factors in manufacturing	0.2	0.4
Minerals in the production of electric transport	0.2	0.4
Mineral1 in the production of conventional transport	0.2	0.4
Mineral1 and production of renewables	0.1	0.4

Source: IMF staff compilation.

[9] Due to data availability, for copper and cobalt we use 2018 data, while lithium data is from 2019. Owing to the volatile nature of nickel exports, we use the average nickel exports and production from 2015 to 2019.

elasticity of substitution of 0.1. Robustness of the findings is tested using a higher elasticity of substitution (0.4 in Table 3.6.2.). This would imply that, for instance, technological progress allows for more substitutability of minerals with other inputs.

3.6.2. Fragmentation Scenarios: Main Channels

The model starts from a steady-state equilibrium, where markets are fully integrated. Then, fragmentation is introduced by eliminating trade in each of the key commodities between the two blocs.

Trade restrictions generate a reallocation of commodity demand across blocs, making trade diversion one of the main propagation channels. When trade across blocs is restricted, the hedger reallocates trade within each bloc, such that the supply and demand of commodities clear at the bloc level at new equilibrium prices. In the case of gas, fragmentation is implemented by restricting trade bilaterally between regions that belong to opposite blocs. The bloc with relatively higher initial supply of each commodity relative to the demand within the bloc (ex-ante net exporting bloc) experiences a decline in the price of the specific commodity.

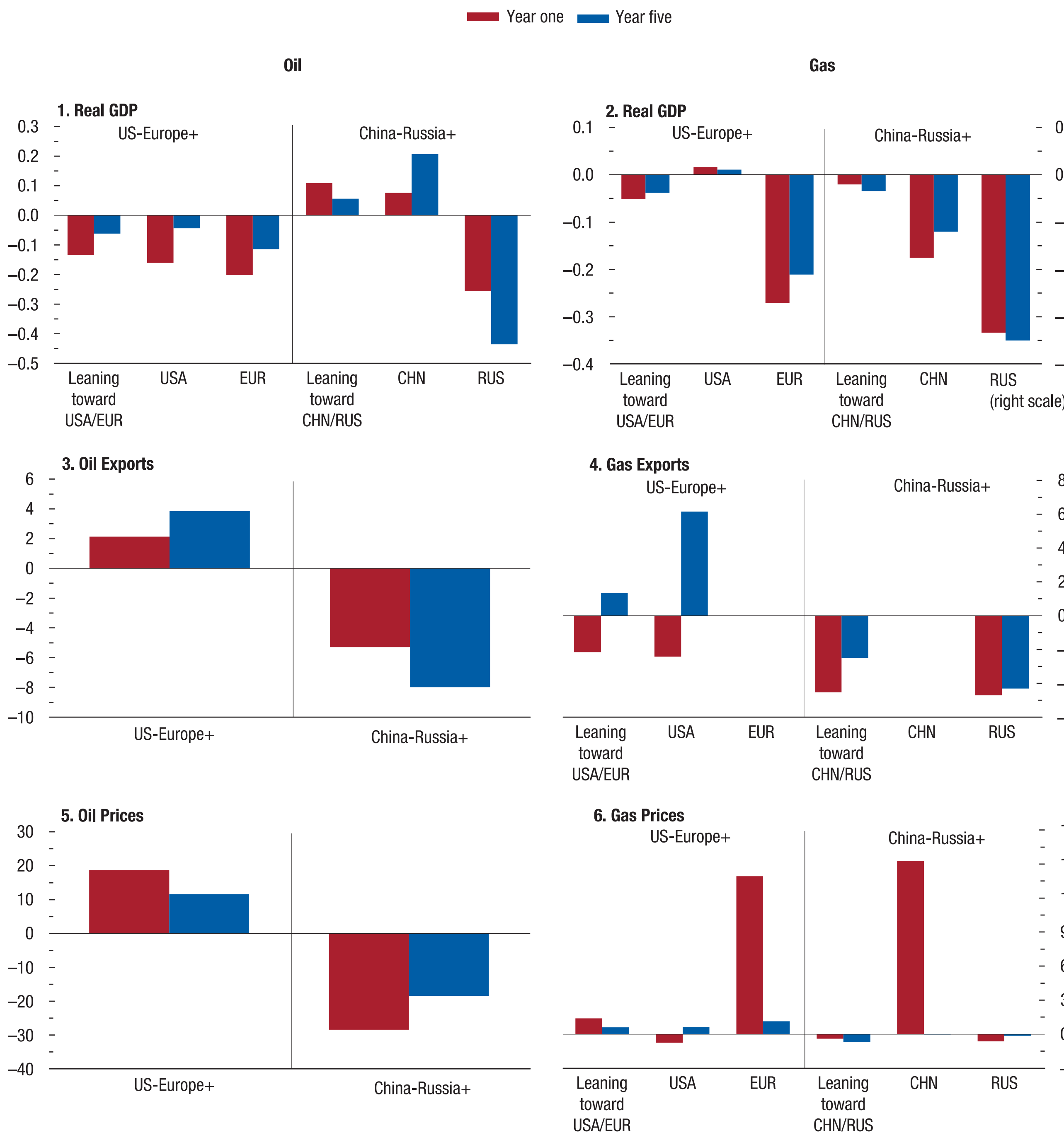
The opposite occurs in the other bloc (ex-ante net importing bloc). Therefore, commodity prices represent another channel through which fragmentation affects economic activity. Finally, trade diversion could be limited in the near term by the presence of rigidities that could slow the adjustment of trading volumes, with more profound effects on prices and aggregate output. To describe the operation of those channels, in Annex

3.6.3. Comparison of the Effects of Fragmentation in Crude Oil and Natural Gas Markets

Starting with fragmentation of the crude oil market, on impact (year 1) oil prices increase by about 18 percent in the US-Europe+ bloc and decline by about 28 percent in the China-Russia+ bloc (see Figure 3.6.3). Initial oil demand is larger than supply in the US-Europe+ bloc, while the opposite occurs in the other bloc. Prices then slightly decline as production and trade adjust. The adjustment happens quite fast as there are no material frictions to oil trade. Traded oil volumes already adjust substantially in the first year, with contained impacts on GDP and inflation. Exports of oil increase within the US-Europe+ bloc, where there is an undersupply of oil, and decrease in the China-Russia+ bloc. Within the same bloc, there are important differences across regions. Ex-ante exporters in an ex-ante exporting bloc, such as Russia and some countries leaning toward the China-Russia+ bloc (e.g., Iraq, Iran), lose from fragmentation because oil prices decline.

Russia faces the largest losses in terms of GDP, as oil exports represent about 50 percent of its total exports, while China and other countries in the same bloc (which, excluding a few, are mostly oil importers) benefit from oil becoming cheaper. In the US-Europe+ bloc, the European Union faces larger losses, as it is a net importer in an ex-ante net importing bloc, where prices increase after fragmentation.

Online Annex Figure 3.6.3. Fragmentation of Oil and Gas Markets
(Percent deviation from baseline)



Sources: IMF, Global Macroeconomic Model for the Energy Transition; and IMF staff calculations.
Note: Region-level results are aggregated to the bloc and world levels using weights based on GDP at purchasing power parity. The bloc including the countries that voted for Russia's withdrawal from Ukraine in the 2022 UN vote is labeled the "US -Europe+ bloc," and the remaining countries are included in the "China-Russia+ bloc."

A potential fragmentation of natural gas markets has a more marked negative impact on GDP and inflation in both blocs. This is because rigidities, such as pipelines, limit trade diversion. This is the case for example with gas supplies from Russia to Europe. The assumption is that in the near term most of the gas provided through pipelines cannot be redirected toward other regions in the China-Russia+ bloc after the fragmentation shock. China also imports more that 60 percent of its gas from countries belonging to the opposite bloc (e.g., Australia) that cannot be quickly replaced with gas supplies from Russia. As a result, the impact on trade flows and inflation are larger with a marked negative impact on GDP in the near-term in both the European Union and China. Russia faces more pronounced losses relative to the case of oil because of a larger role of rigidities.

3.6.4. Fragmentation of Critical Minerals Markets: Impact on the Clean Energy Transition

The fragmentation of the critical minerals markets highlights the importance of the distribution of demand and supply across blocs and at the same time elevated costs and time to build necessary capacity to process and refine minerals. The elevated concentration of mined minerals supply in the hypothetical US-Europe+ bloc leads to steep increases in prices and inflation in the hypothetical China-Russia+ bloc. The heavy use of these minerals, especially *mineral1*, in the manufacturing and construction sectors in countries like China generates a large fall in GDP in the China-Russia+ bloc. The oversupply of those minerals in the US-Europe+ bloc cannot be quickly used in that bloc as processing and refining capacity requires long time to build and scale up. This peculiar rigidity is captured in the model by assuming that after the fragmentation, the US-Europe+ bloc cannot replace immediately the large mineral processing sector in the China-Russia+ bloc. To account for this, a shock to the productive use of minerals is fed through the model. The magnitude of the shock is proportional to the China-Russia+ imports of minerals from the US-Europe+ bloc in the initial equilibrium before fragmentation.[10] As a result, the impact of fragmentation on the US-Europe+ bloc is also a decline in GDP.

Given the projected importance of minerals for the green transition, the increase in prices after a potential fragmentation can be even more relevant in the medium run. Thus, the model is used to examine how fragmentation could affect the green transition. To start, the demand for copper, nickel, cobalt, and lithium is assumed to increase in the future as projected by the IEA (2023) Net Zero Emission scenario (NZE baseline). An increase in investment in renewable energy and EVs consistent with this higher demand up to 2030 is simulated, keeping track of the resulting endogenous increase in the prices of these minerals. The increase in investment in renewables and EVs is stimulated through "green" subsidies in all regions. The baseline assumes that minerals can be traded freely. The fragmentation scenario bans minerals trade across blocs, while leaving the subsidies unchanged like in the baseline.

Fragmentation of the critical minerals markets leads to an increase in mineral prices in both hypothetical blocs in the initial years as the China-Russia+ bloc cannot access minerals that are mined in the US-Europe+ bloc. At the same time, the US-Europe+ bloc does not have built-up

[10] After fragmentation the shock to the productive use of mines is set to mimic the difficulty to use minerals without a previously built-up refining capacity. The shock is set to generate a decline in mineral1 and mineral2 production to mimic the fact that the share of those minerals that cannot be exported to the China-Russia+ bloc after the fragmentation cannot be used in the US-Europe+ bloc. The magnitude of the shock is therefore proportional to the China-Russia bloc import share of those minerals in the initial steady state when markets are perfectly integrated. The shock gradually diminishes to bring the productive use of minerals in the US-Europe+ bloc to the full level of supply by year 10. This simulates the time that it takes to set up a refinery plant (5 to 10 years).

refining capacity to reap the benefits from the relative oversupply of those minerals. That's why prices fall consistent with an oversupply of minerals in that bloc. By 2030, prices are over 20 percent lower in the US-Europe+ bloc and over 200 percent higher in the China-Russia+ bloc, relative to the NZE baseline. On the whole NZE transition path 2023-2030, prices of minerals are on average 300 percent higher on average relative to the NZE baseline in the China-Russia+ bloc, accounting for the spike in prices in the initial years. Fragmentation leads to a decline in investment in renewable energy and EVs at the global level, with much bigger losses, relative to the baselines, in the China-Russia+ bloc.

A key assumption is the constant-return-to-scale technology in the production of renewable energy and EVs. If their production exhibited increasing returns to scale, the US-Europe+ bloc could scale up investment faster than in the baseline. Both effects deliver a decline in renewables and EVs in the US-Europe+ bloc of the magnitude assumed in the benchmark model.

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