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Export Restrictions on Minerals and Metals: Estimation and Analysis of Supply Chain Effects from Zimbabwe's Chromium Ore Export Ban

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Abstract

Export restrictions on industrial raw materials are increasingly common. This paper is the first in a multi-part series that analyzes the impacts of export restrictions on supply chains, with focus on countries' use of export bans on minerals and metals to develop downstream domestic industries. The paper proposes a modeling approach that estimates supply chain effects of upstream export restrictions, illustrated with an application to the Zimbabwe export ban on chromium ore in 2011-2015 and again in 2021. The analysis finds that the 2011 export ban decreased total chromium ore production in Zimbabwe (45 percent) and lowered the price of domestic chromium ore (18.1 percent) due to the elimination of export destinations. This led to an increase in the quantity of ferrochromium produced (15.2 percent) in Zimbabwe as more inputs were exclusively available at a cheaper price. Zooming out, the chromium ore and ferrochromium producer price changes increased average world prices of ferrochromium (used primarily as inputs in stainless steel production) by a negligible 0.04 percent, illustrating that the supply chain segment targeted by the restriction and the exporter's share of global supply influence the global impact of the export restriction.

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Introduction

Export restrictions can be defined as "measures instituted by exporting countries to supervise export flows."[1] These measures include licensing requirements, taxes, quotas, and bans. Amidst recent global macroeconomic shocks—the COVID-19 pandemic and the Russian invasion of Ukraine—and renewed instances of resource nationalism, countries are imposing more export restrictions.[2] A World Trade Organization (WTO) report indicates that from mid-October 2021 to mid-October 2022, WTO members introduced 214 trade-restrictive measures on goods, relative to 376 trade-facilitating measures on goods. As of mid-October 2022, the trade-restrictive measures in place affect an estimated $278 billion of trade globally.[3] This period marked the first occurrence of export restrictions outpacing import restrictions since global monitoring of trade-restrictive measures began in 2009.[4]

Unilateral export restrictions, including export bans, can have global economic consequences. Impacts on a global industry and supply chain vary due to the market share of the exporter, the duration and severity of the restriction, and—particularly in the case of metals and minerals—concentration of reserves. Economic literature has established a link between certain export restrictions and world price uncertainty, which echoes concerns from intergovernmental organizations that economies' unilateral use of export restrictions can prolong market uncertainty after global macroeconomic shocks.[5] For agricultural exports—which were especially subject to export restrictions following Russia's invasion of Ukraine—positive feedback loops ensued as food inflation prompted export bans, which in turn drove food prices higher.[6]

Export restrictions in industrial raw materials are increasingly common. Characteristics of raw materials industries include geographically concentrated production, large firms with market power, capital-intensive production processes, and homogenous products.[7] Increased demand for certain raw materials that are either scarce, highly concentrated in several countries, or both, has also contributed to endowed countries' pursuits of export restrictions. Countries with minerals and metals that are inputs in higher value products in downstream processing use export restrictions as a lever to develop or protect domestic downstream industries. In August 2023, China imposed unilateral export restrictions on gallium and germanium, two metals essential to the production of computer chips, solar panels, and other advanced technology. This followed U.S. export controls on advanced computer chips to China.[8] In September 2023, Malaysia announced a forthcoming export ban on raw rare earth element (REE) ores, citing resource conservation.[9] While Malaysia has only a fraction of REE global reserves, the country is responsible for 8 percent of China's imports of rare earth ores. In October 2023, China, the world's

[1] Bonarriva, Koscielski, and Wilson, "Export Controls: An Overview," August 2009, 1.
[2] WTO, "Report shows increase in trade restrictions", December 6, 2022.
[3] WTO, "Report shows increase in trade restrictions", December 6, 2022.
[4] Import tariffs and quotas are common types of import restrictions.
[5] Adjemian, Petroff, and Robe, "The Political Economy of Export Bans," February 28, 2023; Crosbie, "Export Restrictions on the Rise," June 7, 2022.
[6] Crosbie, "Export Restrictions on the Rise," June 7, 2022.
[7] Fung and Korinek, "Economics of Export Restrictions," May 1, 2013, 1.
[8] Associated Press, "China Restricts Exports of High-Tech Metals," July 4, 2023.
[9] Neodymium, scandium, and yttrium are examples of rare earth elements. Ananthalakshmi and Nguyen, "Malaysia to Ban Export of Rare Earths," September 11, 2023.

largest graphite producer, announced new requirements of export permits for certain graphite products.[10]

Beyond the intent to develop or protect domestic downstream industries, other commonly documented purposes for export restrictions include obligations under international agreements, national security, environmental preservation and resource conservation, cultural or heritage preservation, and public health.[11] Historically, higher-income countries have more often cited national security and international agreement obligations as the purpose for export restrictions, while lower-income countries tend to use resource conservation and public health as reasons to restrict exports.[12] Studies have examined both global and domestic impacts of export bans on agricultural commodities and raw materials, and indicate that the environmental and economic objectives of the bans tend to be unsuccessful. For example, Laos imposed an export ban on logs and sawnwood in 2016 to mitigate high deforestation rates and bolster domestic wood production. The domestic industry largely faltered, however, as it was too small and reliant on demand from exports of sawnwood.[13] While official imports of timber from Laos fell to almost a tenth of what they were in 2016 by 2017, the rate of tree loss relative to recorded exports led to wide speculation that loggers were illegally sending exports through Cambodia, weakening the impact of the ban on deforestation rates.[14] An analysis of Ethiopia's export ban on teff, a common grain with increasing global demand, found that the revenue gained from export tariffs after removing the ban would largely benefit actors further down the value chain, such as food distributors and storage operators, rather than crop producers.[15]

In an economy with abundant mineral resources and a robust mining industry, several factors can limit or prevent development of downstream processing: asymmetric market power, economies of scale, input availability, tariff escalation, closeness to market, and business environment.[16] One analysis concluded that few, if any, historical export bans have successfully promoted greater downstream processing through restrictions on upstream, unprocessed products.[17]

This paper series analyzes the impacts of export restrictions on supply chains, with focus on export bans of minerals and metals that are implemented by countries to develop downstream industries domestically. The first paper estimates the impact of the Zimbabwe export restrictions on chromium ore in 2011 and again in 2021. It begins with an analysis of recent trends in export restrictions. Then, a model-based analysis is conducted to estimate the effects of the Zimbabwe export ban on ferrochromium and stainless steel industries. The modeling approach is applied to both the 2011 and 2021 Zimbabwe chromium ore export bans to compare differing effects over time.[18] In addition, a simple

[10] Liu and Patton, "China tightens exports of key battery material," October 20, 2023.
[11] Bonarriva, Koscielski, and Wilson, "Export Controls: An Overview," August 2009, 12.
[12] Bonarriva, Koscielski, and Wilson, "Export Controls: An Overview," August 2009, 13.
[13] To and Canby, "Laos Log and Sawnwood Export Ban: Impacts on the Vietnam–Lao Timber Trade," March 2017.
[14] Cook, "Is Laos Missing the Forest for the Trees?," January 6, 2018; Souksavanh, "Logging Continues in Laos as Provinces Ignore Export Ban," December 7, 2016.
[15] Sankaranarayanan et al., "Ethiopia's Policy on the Export Ban of Teff," 2020.
[16] Östensson, "Promoting Downstream Processing," July 1, 2019.
[17] Östensson, "Promoting Downstream Processing," July 1, 2019.
[18] The term "chromium ore" used throughout this paper to refer to the raw material is also commonly called "chromite ore" in publications and reports. Chromite ore is the mineral ore from which chromium is extracted. ICDA, "Chrome ore," accessed November 29, 2023.

difference-in-differences (DID) regression model is used to compare modeled outcomes with actual changes in the data from 2011-2015. The second paper in this series provides analysis on the Indonesia nickel ore export ban, detailing global nickel resources, the Indonesian nickel industry, and developments in Indonesia's downstream nickel sector since the export ban was implemented.[19]

Export Restrictions on Industrial Raw Materials

The Organisation for Economic Co-operation and Development (OECD) maintains a database on countries' export restrictions on industrial raw materials–largely minerals, metals and wood.[20] The database catalogs export restrictions active globally during 2009-2021, providing information on the product type at the Harmonized System (HS) 6-digit subheading level, type of export restriction, dates of introduction, change, or termination of measure, and in some cases, reported purpose of the measure.[21] Types of export restrictions imposed include captive mining, export quotas and taxes, domestic market obligation, licensing requirements, and export prohibition (export ban), among others. During 2009 to 2021, exporters introduced or reintroduced 4,154 export restrictions on industrial raw materials, with the greatest share being forms of export taxes[22] (36.1 percent), followed by licensing requirements (29.2 percent). Figure 1 presents the number of export restrictions by type introduced each year. Export bans as a share of total restrictions introduced were highest in 2010 (26.2 percent), 2020 (22.5 percent), and 2021 (21.2 percent).

[19] Guberman, Perry, and Schreiber, "Export Restrictions on Minerals and Metals: Indonesia's Export Ban of Nickel", 2024.
[20] Export restrictions on primary agricultural products are reported in a separate inventory.
[21] OECD, "Export Restrictions on Industrial Raw Materials," accessed July 7, 2023.
[22] The OECD inventory differentiates 'export tax' from 'fiscal tax on exports', which are aggregated for data presentation in this paper.

Figure 1 Export Restrictions Introduced on Industrial Raw Materials Globally

Source: OECD, "Inventory on export restrictions on Industrial Raw Materials," accessed various dates.

Export Restrictions on Minerals and Metals

The 4,154 export restrictions for industrial raw materials introduced or reintroduced[23] during 2009-21 are classified under 15 chapters and 469 HS 6-digit subheadings.[24] Roughly 17 percent of the export restrictions introduced during 2009-21 occurred under Chapter 26, covering ores, slag, and ash. This paper series focuses on ore export bans, which impact downstream industries with greater value-addition. During the 12-year inventory period, exporters introduced 229 restrictions on various ores and concentrates. The top five minerals subject to export restrictions during 2009-21 were copper, iron, molybdenum, titanium, and zirconium, collectively accounting for 48.9 percent of total export restrictions introduced (table 1).

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[23] Reintroduction is defined in the inventory as "measure expired and was introduced again without any changes except for the date of introduction and/or end date of measure." OECD, *Methodological note to the Inventory of Export Restrictions on Industrial Raw Materials,* October 12, 2022, p.8.

[24] The Harmonized System (HS) is a classification system for traded products that uses standardized numbering. ITA, "Harmonized System (HS) Codes," accessed November 12, 2023.

Table 1 Export Restrictions by Ore Type under Chapter 26, 2009-2021

Ore Type	Export Ban	Export Tax	Licensing requirement	Qualified exporters list	Other Export Restriction Measures	Total
Copper	2	17	5	0	4	28
Iron	0	6	6	4	8	24
Molybdenum	0	24	0	0	0	24
Titanium	0	12	3	1	2	18
Zirconium	1	7	5	1	4	18
Niobium/ tantalum/ vanadium	0	3	4	0	7	14
Precious metal	1	5	2	1	4	13
Silver	1	2	4	0	6	13
Aluminum	1	4	2	0	4	11
Cobalt	2	3	4	0	1	10
Nickel	1	3	4	0	2	10
Manganese	0	1	3	2	2	8
Chromium	1	1	1	2	2	7
Tin	0	4	3	0	0	7
Tungsten	0	5	2	0	0	7
Antimony	0	1	3	0	0	4
Lead	0	0	2	0	2	4
Roasted iron pyrites	0	0	2	0	2	4
Zinc	0	0	1	0	2	3
Other	0	1	1	0	0	2
Total	10	99	57	11	52	229

Source: OECD, "Inventory on export restrictions on Industrial Raw Materials," accessed various dates.
Note: Each product description covers ores and concentrates.

Three countries—Democratic Republic of the Congo, Indonesia, and Zimbabwe—are responsible for the ten ore export bans introduced between 2009 and 2021 (table 2). All three developing countries have established mining industries that generate substantial revenue for the economies and introduced ore export bans to protect and develop domestic downstream industries. Indonesia accounts for seven of the bans at the HS 6-digit subheading level in the database. These were introduced as part of Indonesian Parliament's 2009 Mining Law on Mineral and Coal Mining, which prohibited exports of select types of unprocessed ores and obligated domestic industries to process and refine ores in Indonesia.[25] Several additional export bans introduced before 2009 were in place during the same period: iron ores and concentrates and roasted iron pyrites in Saudi Arabia and precious metal ores and concentrates in Philippines. This paper uses the export ban of chromium ore in Zimbabwe as an applied case for a model-based analysis of mineral export bans on downstream markets—in this case, the ferrochromium and stainless steel industries.

[25] Republic of Indonesia, Law on Mineral and Coal Mining, Pub. L. No. 4/2009, 39, (January 12, 2009), (accessed December 18, 2023); USGS, *Resource Nationalism in Indonesia*, 2016.

Table 2 Export Bans Introduced on Ores and Concentrates under Chapter 26, 2009-2021

Country Introducing Ban	Product (Ores and Concentrates)	HS Subheading Specified	Dates	Reported Purpose of Measure
Democratic Republic of the Congo	Copper; cobalt	2603.00; 2605.00	July 8, 2017-August 22, 2020	Promote further processing, value added
Indonesia	Copper; nickel; cobalt; aluminum; zirconium; silver; precious metal	2603.00; 2604.00; 2605.00; 2606.00; 2615.10; 2616.10; 2616.90	January 13, 2014	Protect local downstream industry; promote further processing, value added
Zimbabwe	Chromium	2610.00	April 1, 2011- June 8, 2015	Promote further processing, value added

Source: OECD, "Inventory on export restrictions on Industrial Raw Materials," accessed various dates.

Application: Zimbabwe and Chromium Ore

In this section, a model-based analysis is applied to the series of chromium ore (HS subheading 2610.00) export bans in Zimbabwe, first from 2011 -2015 and reintroduced in 2021. The section first introduces the chromium ore industry and its downstream supply chain for stainless steel production before describing the state of the industry in Zimbabwe.

Chromium Ore and the Global Supply Chain

Chromium is a hard, gray metal mostly used in the steel industry as an alloying element[26] because of its hardness and corrosion resistance.[27] More than 95 percent of chromium consumption is in metallurgical applications.[28] Of metallurgical chromium demand, 78 percent is attributed to stainless steel production.[29] Ferrochromium, an alloy form of chromium, is essential in the manufacturing of stainless steel, which has higher relative chromium content and—as such—corrosion resistance than other steel forms. Most stainless steel contains roughly 18 percent chromium and is required to contain a minimum of 10.5 percent chromium.[30] Niche chromium chemical and refined metal accounts for 3 percent of global chromium consumption, with downstream applications including leather tanning, metal finishing, wood preservatives, paints, and glazes.[31]

Kazakhstan, South Africa, and India collectively hold nearly 95 percent of reported global reserves of chromium ore.[32] However, Zimbabwe is reported to hold roughly 12 percent of global reserves of high-grade chromium ore, second only to South Africa.[33] Zimbabwe's chromium ore has an estimated average

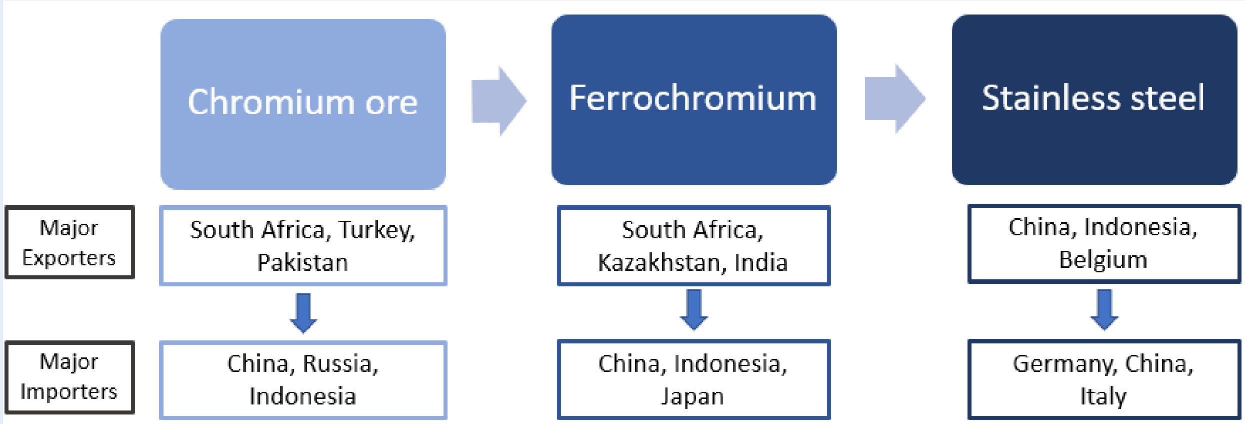
[26] Metal alloys are those metals that can be mixed to form a new substance with superior properties.
[27] USGS, "Chromium," 2010.
[28] Fastmarkets, "Industrial Minerals: Chrome and Chromite," accessed September 1, 2023.
[29] Fastmarkets, "Industrial Minerals: Chrome and Chromite," accessed September 1, 2023.
[30] USGS, "Chromium," 2010.
[31] Fastmarkets, "Industrial Minerals: Chrome and Chromite," accessed September 1, 2023.
[32] USGS, *Minerals Commodity Summaries 2023,* 2023, p. 57.
[33] Stibbs, "Zimbabwe Chrome ore Export Ban," *Fastmarkets,* August 12, 2021. Throughout the paper, 'tons' is used as shorthand for metric tons.

chromium content of 48 percent, which is priced at a premium relative to South African metallurgical grade concentrate.[34] This higher content is ideal for ferrochromium processing, as ferrochromium contains between 50 and 70 percent chromium.[35]

Roughly twenty countries operate chromite mines globally, including South Africa, Kazakhstan, Turkey, India, and Zimbabwe. [36] Global chromite production doubled in the last decade, largely due to capacity expansion of chromite mining in South Africa and Zimbabwe driven by chromium price spikes in 2016-2017 and rising ferrochromium and stainless steel demand.[37] In 2019, South Africa and Turkey accounted for roughly 38 percent and 22 percent of the 44.8 million metric tons of chromite produced globally, respectively.[38] Zimbabwe was the sixth largest producer globally, with roughly 1.5 million metric tons of chromite produced, or 3.5 percent of the global total.[39]

The top five exporters of chromium ore in 2022 were South Africa (77 percent of global export value), Turkey (11 percent), Kazakhstan (5 percent), Pakistan (3 percent), and the Netherlands (1 percent). The main trade flow in the chromium supply chain upstream of stainless steel production is between South Africa and China, the leading exporter and importer of both chromium ore and ferrochromium, respectively (figure 2). Indonesia is in a similar position to China, as a major importer of both chromium ore and ferrochromium and the second largest global exporter of stainless steel products. Zimbabwe was the 7th largest chromium ore exporter and 13th largest ferrochromium exporter before the 2021 export ban went into effect.[40]

Figure 2 Global Chromium Ore Supply Chain for Stainless Steel



Source: S&P Global, GTAS, accessed November 29 and 30, 2023; Data are from HS subheadings and headings 2610.00; 7202.41; 7202.49; 7218; 7219; 7220; 7221; 7222.
Note: The top three global exporters and importers of each product group by value from 2018-2022 are listed.

[34] Davies, Janie, "Zimbabwe will become a significant player in premium chrome ore market," June 21, 2018.
[35] ICDA, "Ferrochrome," n.d., accessed November 29, 2023.
[36] Fliess, Idsardi, and Rossouw, *Export Controls and Competitiveness in African Mining*, July 12, 2017.
[37] Fastmarkets, "Industrial Minerals: Chrome and Chromite," accessed September 1, 2023.
[38] Fastmarkets, "Industrial Minerals: Chrome and Chromite," accessed September 1, 2023.
[39] Barry, James, *2019 Minerals Yearbook- Zimbabwe,* USGS, July 2023, pp. 47.1- 47.2.
[40] Rankings for Zimbabwe's exports are based on value of exports from 2018-2021.

Chromium Ore Industry in Zimbabwe

Zimbabwe has an extensive and diversified mining industry spanning roughly 40 minerals, predominantly platinum group metals, chrome, gold, coal, and diamonds.[41] The mining sector accounts for about 13 percent of the country's gross domestic product (GDP), more than 60 percent of Zimbabwe's exports, and more than 50 percent of foreign direct investment (FDI).[42] In 2019 the Government of Zimbabwe announced a goal to reach a $12 billion mining sector by 2023.[43] As of 2023, Zimbabwe produces roughly one million tons of chromium ore per year, of which 25 percent is used in the domestic downstream industry for ferrochrome, while most of the remainder is exported to China. Zimbabwe constitutes 4 percent of China's 14 million tons of chromium ore imports per year.[44]

In its 2021-2025 National Development Strategy, the Republic of Zimbabwe highlighted the establishment of ferrochrome processing plants as a key objective to spur job creation, increase foreign currency earnings, and increase steel manufacturing capacity in the country. Part of this priority includes a target to add five new ferrochrome processing facilities by 2025.[45] The domestic industry in Zimbabwe had 22 privately owned smelters as of 2021. Chinese-based Tsinghan Holding Group—the largest global stainless steel company—holds the largest ownership of the chrome industry in Zimbabwe. Tsinghan owns a 100,000 metric tons per year (tpy) ferrochromium plant and a 350,000 tpy coke plant.[46] Its subsidiary, Zhejiang Dinson, is constructing a carbon steel plant, iron ore mine, and a 500,000 tpy ferrochromium plant in Kwekwe, Zimbabwe, set to open in 2024.[47] Zimasco, owned by the Chinese state-owned trading firm Sinosteel, is another major producer in Zimbabwe with capacity of ferrochrome estimated to be 300,000 tpy as of 2024.[48] Table 3 highlights some of the latest investments in Zimbabwe's chromium and downstream industries.

[41] ITA, "Mining and Minerals," August 2, 2022.
[42] Mining Zimbabwe, "Key mining projects and plant upgrades," June 6, 2023.
[43] Mavhunga, "Africa's Move from Raw Material Exports toward Mineral Value Addition," May 16, 2023.
[44] Mavhunga, "Africa's Move from Raw Material Exports toward Mineral Value Addition," May 16, 2023.
[45] In the 2021-2025 period, Zimbabwe intends to increase its number of ferrochrome processing facilities from six to eleven by 2025. Republic of Zimbabwe, *National Development Strategy 1*, November 16, 2020, 103.
[46] Coke is a is a processed form of coal that is used in blast furnaces that make steel from molten iron. American Iron and Steel Institute, "Glossary," https://www.steel.org/steel-technology/steel-production/glossary/, accessed October 24, 2023.
[47] Mavhunga, "Africa's Move from Raw Material Exports toward Mineral Value Addition," May 16, 2023.
[48] Stibbs, "Zimbabwe Chrome Ore Export Ban," August 12, 2021; Reuters, "Sinosteel to invest $1 bln in Zimbabwe," May 15, 2018.

Table 3 Investments in Zimbabwe's chromium and downstream industries since 2021

Firm	Investment
Jinyi	From 2021-2023, the China-based firm invested $7.1 million to increase its ferrochrome production capacity in Zimbabwe at least 20 percent by the end of 2024.
Zimasco	In April 2023, the China-based firm completed upgrades and expansion at its high-carbon ferrochromium smelter, producing an additional 70,000 metric tons of ferrochromium. From 2021-2023, Zimasco invested $6.8 million to upgrade ferrochromium production, expected to increase capacity by 120 percent by 2025.
African Chrome Fields (ACF)	In Fall 2023, South Africa-based ACF completed a $2 billion investment in an aluminothermic smelting plant near its Kwekwe mine. The novel smelter can produce ultra-low-carbon, high-grade ferrochrome in a fraction of the time of conventional smelters. At 0.05 percent carbon and up to 65 percent chromite, the produced ferrochromium would reportedly be among the highest-quality product globally.
Dinson (Disco)	In April 2024, Dinson, a subsidiary of China's largest steel company Tsinghan, begins operation at Zimbabwe's largest integrated steel plant, producing 600,000 metric tons of carbon steel in phase I with an anticipated full production capacity of more than 5 million metric tons annually. The investment totaled $1.5 billion.

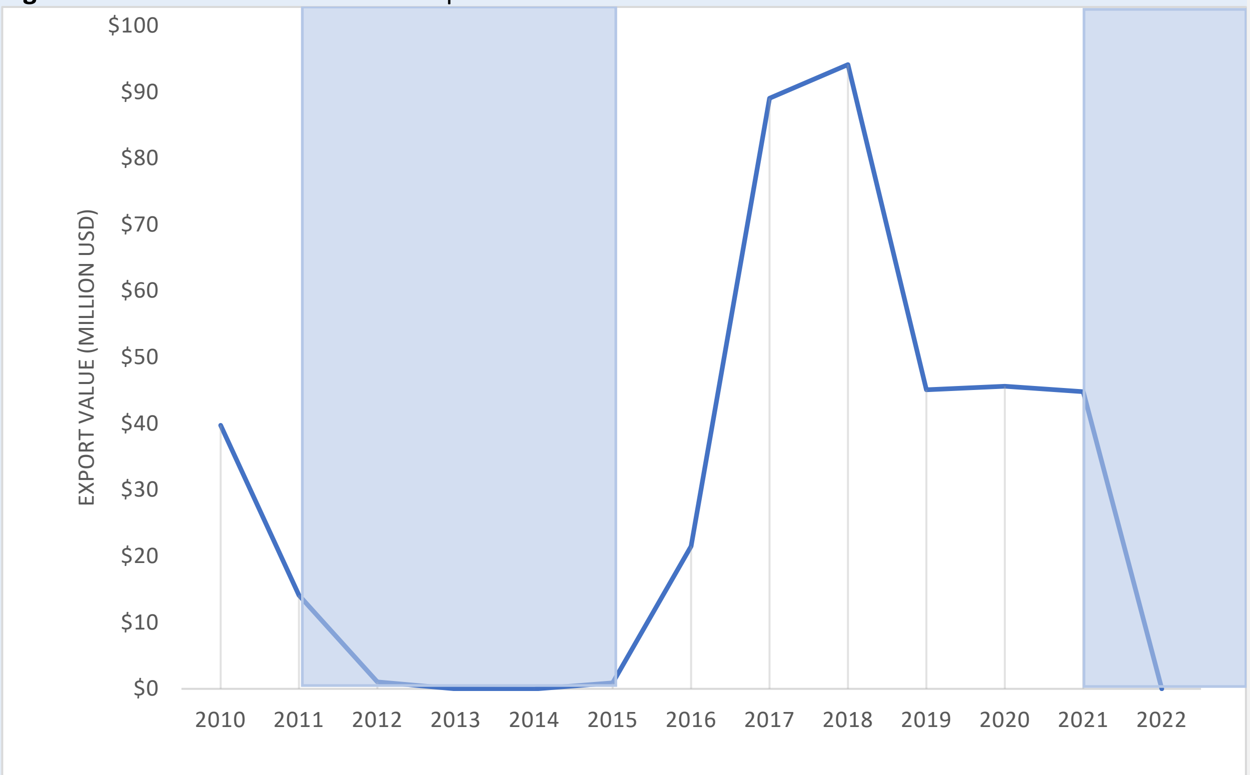
Sources: The Herald, "Zimbabwe sees surge in mining investments," November 8, 2023; Zhuwakinya, Martin, "Commissioning of Zimbabwe ferrochrome plant under way," August 25, 2023; The Herald, "US $1,5 billion Dinson Mine commences operations April," January 15, 2024.

Chromium Ore Export Bans: 2011-2015 and 2021-Present

In 2011, the Government of Zimbabwe banned chromium ore and concentrates exports (HS 2610.00) to push domestic chromium ore producers to develop downstream production capacity for ferrochromium. The government gave producers eighteen months to establish smelting capabilities. The ban, however, did not successfully spur downstream development: during 2011-2015, Zimbabwe's chromium ore output decreased by 64.8 percent, and two major producers—Zim Alloys and Zimasco—shut down. The government lifted the ban in 2015 after no notable increase in smelted chrome production.[49] In 2016, the export value of chromium ore (HS 2610.00) from Zimbabwe rebounded and continued to increase for several years, peaking as the third largest global exporter at $94.1 million (3.5 percent of global export value) in 2018 (figure 3).

[49] Huni, Sheperd "The Mining Regulatory Framework and Its Impact on the Drive for Beneficiation in Zimbabwe between 2009 and 2016," 2018.

Figure 3 Zimbabwe Chromium Ore Export Value to World



Source: S&P Global, GTAS, accessed November 27, 2023; Data are from HS subheading 2610.00.

Note: Shading indicates periods with the chrome ore export ban in effect.In 2021, Zimbabwe again initiated an export ban on chromium ore, with a follow-up ban on chrome concentrates beginning in July 2022.[50] Trade data indicate Zimbabwe exported chromium ore in 2021 (2 percent of global export value) but did not export chromium ore in 2022 (figure 2).

Developments in Zimbabwe's chrome industry since the 2011 ban suggest that the most recent export ban may attract more foreign investment (see table 3). Since the removal of the first ban in 2015, Zimbabwe has received substantial foreign investment in its mining industry, leading to increased downstream processing capacity (i.e., building of facilities and processing equipment) for chromium ore. China is the top foreign investor in Zimbabwe's mining industry, and an investigation by non-profit Information Development Trust found that Chinese investments in Zimbabwe increased substantially post-2017.[51] This suggests that ferrochromium production capacity in Zimbabwe may continue to expand with the 2021 ban in place, achieving the objective first set out by the country's 2011 ban on chromium ores.

However, some experts remain skeptical that the domestic industry has expanded quickly enough for the most recent ban to result in the level of growth in the downstream ferroalloy sector needed to offset

[50] Mavhunga, "Africa's Move from Raw Material Exports toward Mineral Value Addition," May 16, 2023.
[51] The Standard, "Zimbabwe's Look East Policy Bears Fruit," November 12, 2023.

income losses from the decline in ore exports.[52] Industry observers note that other chromium ore exporters in the global market, including Turkey and Pakistan, may stand to benefit from the compound ban of ores and concentrates as Zimbabwe's competitively priced chromium ore is removed from the market. With the most recent export ban in place, downstream ferrochromium producers (including many in China), have experienced higher prices of chrome inputs from other countries.[53]

Estimated Effects of the Zimbabwe Chromium Ore Export Ban in 2011

A calibrated economic model can be used to estimate the impact of an upstream export restriction of raw materials such as minerals and metals on downstream industries in a supply chain. The modeling approach uses a partial equilibrium framework that can be applied to many types of supply chain disruptions.[54] This paper focuses on linkages between upstream minerals and downstream industries that consume these minerals, by analyzing the Zimbabwe export ban on chromium ore from 2011 to 2015 and again in 2021.

Estimating the effect of an export ban can be difficult for several reasons. First, a researcher may want to compare market outcomes (data) from a year that the ban is in place to market outcomes (data) in the year that the ban is not in place. However, it can be difficult to isolate the impact of the ban from other exogenous shocks that affect the data. An economic simulation model is a useful tool for isolating the impact of the ban from other global market forces and outcomes. The proposed model compares actual data in the year before the export ban to a counterfactual scenario where the export ban is added to the market. The methodology is described in more detail in the next section.

Second, a general equilibrium (GE) model is a commonly used method to capture both direct and indirect effects of trade policies.[55] However, a GE model often has broad, pre-defined industry classifications that may not match the disaggregated level of the product banned from exportation and may not adequately capture the specific supply chain linkage of interest. For example, in the case of the Zimbabwe chromium ore export ban, the Global Trade Analysis Project (GTAP) database has a sector for mining of metal ores (GTAP sector oxt) that aggregates all metal mining activities (including chromium ore).[56] The sector for iron and steel (GTAP sector i_s) includes both ferrochromium and stainless steel, the key industries downstream of chromium ore.[57] Considerable work would be needed to split out chromium ore, ferrochromium, and stainless steel from the aggregated groups to isolate direct impacts of the export bans on most affected industries. A partial equilibrium modeling approach allows

[52] Stibbs, "Zimbabwe Chrome Ore Export Ban," August 12, 2021.
[53] Stibbs, "Zimbabwe Chrome Ore Export Ban," August 12, 2021.
[54] Contrasting partial equilibrium to general equilibrium, a partial equilibrium analysis focuses on one market or multiple markets, whereas a general equilibrium model includes all markets.
[55] For example, see the USITC's report, "Economic Impact of Trade Agreements Implemented under Trade Authorities Procedures, 2021 report."
[56] The GTAP database is a global database of bilateral trade flows, production, consumption and intermediate use of commodities and services.
[57] As described in the Application section below, chromium ore is essential in stainless steel production due to its corrosion resistance. Chromium ore is first processed into ferrochromium, an iron-chromium alloy, and then used in stainless steel production.

researchers to take advantage of rich industry-level data and flexible equations to model the supply chain of interest.

Equations

The model equations are described in this section in flexible notation to allow for customization to a specific export ban. The model equations closely follow the equations described in Schreiber (2023) with modifications for the policy changes and calibration methods. This is a partial equilibrium model with two industries (an upstream and a downstream), one supply chain linkage, and multiple country markets.[58] Index *i* refers to the location of upstream producers, *j* to the location of downstream producers, and *k* to the location of consumers. Index *u* refers to the upstream industry and index *d* refers to the downstream industry. The price p_{ui} is the price of the upstream product that is produced in country *i*. Equation (1) is the price index of the upstream product in country *j*, where b_{uij} are calibrated demand asymmetry parameters and σ_u is the constant elasticity of substitution across sources of the upstream product:

$$z_j = \left(\sum_{\mathrm{i}} \left(b_{uij}\, p_{ui}^{1-\sigma_u} \right) \right)^{\frac{1}{1-\sigma_u}} \qquad (1)$$

Equation (2) is the downstream price index P_k, where p_{dj} is the price of the downstream good produced in country *j*, σ_d is the elasticity of substitution across downstream varieties, and b_{djk} are the downstream demand asymmetry parameters:

$$P_k = \left(\sum_{\mathrm{j}} \left(b_{djk}\, p_{dj}^{1-\sigma_d} \right) \right)^{\frac{1}{1-\sigma_d}} \qquad (2)$$

The downstream prices p_{dj} are a function of the upstream prices they use as inputs. Equation (3) represents the price of the downstream product that is produced in country *j*, where c_j is a cost parameter and w_j is the price of all other production inputs and treated as exogenous in the model.[59] The upstream good and all other production inputs are consumed by the downstream in fixed proportions:

$$p_{dj} = \left(w_j + c_j\, z_j \right) \qquad (3)$$

Demand for upstream goods produced in country *i* by all destinations *j* and consumed in *k* is represented in equation (4). This is a modified version of a constant elasticity of substitution (CES) demand equation that incorporates both upstream and downstream prices:

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[58] We model the Zimbabwe, China, and rest of world (ROW) markets for both chromium ore and ferrochromium. With this flexible notation, it would be straightforward to isolate another market from the ROW category. Choice of markets depends on the number of significant export destinations from the country imposing the export ban.
[59] The w_j variable could be interpreted as wages if labor was the only factor of production. It is exogenous in the model and held constant in the counterfactual.

$$q_{ui} = \sum\nolimits_{k}\sum\nolimits_{j}\left(\frac{k_k\ c_j\ b_{uij}\ b_{djk}}{p_{ui}}\right)\left(\frac{p_{dj}}{P_k}\right)^{1-\sigma_d}\left(\frac{z_j}{p_{dj}}\right)\left(\frac{p_{ui}}{z_j}\right)^{1-\sigma_u} \qquad (4)$$

Demand for downstream goods produced in country *j* and consumed in *k* is represented by equation (5):

$$q_{dk} = \sum_{j} k_k b_{djk}\ P_k{}^{\sigma_d-1} p_{dj}{}^{-\sigma_d} \qquad (5)$$

Upstream supply is modeled with a calibrated supply curve with a constant price elasticity of supply (ε_{ui}), where a_{ui} is a calibrated supply parameter:

$$q_{ui} = a_{ui}\ p_{ui}{}^{\varepsilon_{ui}} \qquad (6)$$

In equilibrium, the supply of each upstream variety is equal to the demand in all downstream markets. Therefore, for each *i*:

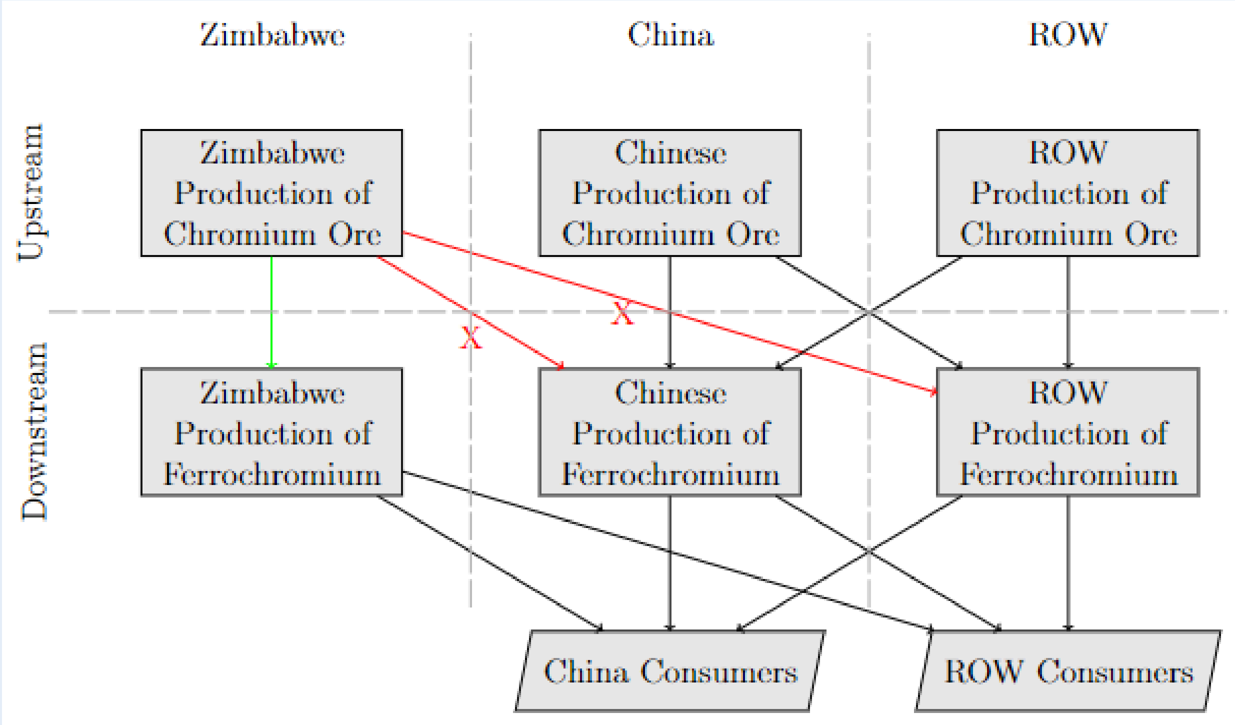
$$a_{ui}\ p_{ui}{}^{\varepsilon_{ui}} = \sum\nolimits_{k}\sum\nolimits_{j}\left(\frac{k_k\ c_j\ b_{uij}\ b_{djk}}{p_{ui}}\right)\left(\frac{p_{dj}}{P_k}\right)^{1-\sigma_d}\left(\frac{z_j}{p_{dj}}\right)\left(\frac{p_{ui}}{z_j}\right)^{1-\sigma_u} \qquad (7)$$

Equation (7), along with the first six equations, describe the equilibrium in the market. The methodology is operationalized by calibrating the model equations to actual data in the year before the export ban enters into force. Then, the model applies the export ban and simulates a market equilibrium set of prices and quantities with export destinations removed from the affected country. The estimated effects of the export ban are the difference between actual data with no export ban in place, and a counterfactual where the export ban is implemented.

In this analysis of Zimbabwe's export restrictions, the impact of the ban is measured as the difference between the actual market outcomes in the year before the ban (2010) and a counterfactual scenario where the ban is applied.[60] In the counterfactual, the model imposes the export ban on Zimbabwean exports of chromium ore. Then the model simulates a new equilibrium set of prices and quantities of production and trade with the export ban in place, for all industries and countries included in the model. The upstream industry in the model is chromium ore mining. The downstream industry is ferrochromium production. Both the upstream and downstream industries have three markets in the model: Zimbabwe, China, and Rest of World (ROW). In the upstream baseline, Zimbabwe producers mine chromium ore and either ship it directly to domestic downstream ferrochromium producers or export to China and ROW. China also mines chromium ore, though in smaller quantities, all of which is sent to Chinese ferrochromium producers and ROW producers. Zimbabwe does not import chrome from China or ROW for ferrochromium production, as reflected in their trade statistics. In the downstream, Chinese ferrochromium producers use both domestic chromium ore and imports of chromium ore from the rest of the world to produce ferrochromium. Consumers of ferrochromium, primarily stainless steel manufacturers, buy from Zimbabwe, China, and ROW producers. The flows between segments of the supply chain and countries are illustrated in figure 4.

[60] The year 2010, the year before the Zimbabwe export ban, was chosen as the baseline for the model to illustrate how a researcher could apply this methodology in an ex-ante analysis.

Figure 4 Model structure as applied to the Zimbabwe chromium ore export ban analysis



Source: Authors' drawing based on trade and production data described above. This flowchart is a simplified representation of the interrelationships between chromium ore and ferrochromium producers and consumers. The red lines indicate the trade flows eliminated in the counterfactual, and the green lines indicate the flows that will remain available to Zimbabwe producers of chromium ore.

Figure 4 is drawn based on 2010–2012 trade and production data. The close trading relationship between Zimbabwe and China simplifies the model structure; before the chromium ore ban, Zimbabwe sent most of its chromium ore to China for use in ferrochromium production. In a supply chain with multiple major export destinations, it may have been important to isolate multiple countries from the ROW grouping, expanding the number of data requirements. Contextualizing equation (1) in this application of the model, with Zimbabwe labeled "A", China labeled "B" and ROW labeled "C", supply and demand of Zimbabwe chromium ore is expressed on the left-hand side and right-hand side, respectively:

$$a_{uA}\, p_{uA}{}^{\varepsilon_{uA}} = \sum\nolimits_{k\in\{A,B,C\}} \left(\left(\frac{k_k\, c_A\, b_{uAA}\, b_{dAk}}{p_{uA}}\right) \left(\frac{p_{dA}}{P_k}\right)^{1-\sigma_d} \left(\frac{z_A}{p_{dA}}\right) \left(\frac{p_{uA}}{z_A}\right)^{1-\sigma_u} + \left(\frac{k_k\, c_B\, b_{uAB}\, b_{dBk}}{p_{uA}}\right) \left(\frac{p_{dB}}{P_k}\right)^{1-\sigma_d} \left(\frac{z_B}{p_{dB}}\right) \left(\frac{p_{uA}}{z_B}\right)^{1-\sigma_u} + \left(\frac{k_k\, c_C\, b_{uAC}\, b_{dCk}}{p_{uA}}\right) \left(\frac{p_{dC}}{P_k}\right)^{1-\sigma_d} \left(\frac{z_C}{p_{dC}}\right) \left(\frac{p_{uA}}{z_C}\right)^{1-\sigma_u} \right)$$

Supply and demand for China and ROW are written similarly.

Data Requirements

This section describes the data requirements and sources used to set up the baseline of the model and calibrate the equations. The model requires production data for the upstream product and the downstream product for each country modeled. For minerals and metals, including chromium ore, global production data are available in the U.S. Geological Survey Minerals Yearbooks and the World Metal Statistics Yearbooks from the World Bureau of Metal Statistics. Ferrochromium production data was obtained from the U.S. Geological Survey Minerals Yearbooks.[61] Production data for minerals were reported in quantities and required conversion to values using an estimated unit value (see note below table 4). The model also requires international trade data by HS code that can be obtained from the United Nations Comtrade database. Mirror data (world imports from Zimbabwe) was used because Zimbabwe does not report export data. Table 4 lists data inputs used in the model to build this structure.

Table 4 Data inputs for Zimbabwe export ban model, 2010

Variable	2010 Value (millions of $)	Source
Production data*		
Zimbabwe chromium ore production value	$109.56	Estimated using the USGS world mineral statistics data and commodity surveys
China chromium ore production value	$51.69	Estimated using the USGS world mineral statistics data and UN Comtrade data
ROW chromium ore production value	$10,625.59	Estimated using the USGS world mineral statistics data and UN Comtrade data
Zimbabwe ferrochromium production value	$204.30	Estimated using the USGS minerals yearbooks and UN comtrade data
China ferrochromium production value	$6,153.60	Estimated using the USGS minerals yearbooks and commodity surveys
ROW ferrochromium production value	$18,137.74	Estimated using the USGS minerals yearbooks and commodity surveys
Trade data		
China chromium ore imports from Zimbabwe	$48.39	UN Comtrade data
ROW chromium ore imports from Zimbabwe	$8.66	UN Comtrade data
China chromium ore imports from ROW	$2,348.75	UN Comtrade data
ROW chromium ore imports from China	$0.76	UN Comtrade data
China ferrochromium imports from Zimbabwe	$52.46	UN Comtrade data
ROW ferrochromium imports from Zimbabwe	$151.84	UN Comtrade data
ROW ferrochromium imports from China	$179.68	UN Comtrade data
China ferrochromium imports from ROW	$2,011.35	UN Comtrade data

Notes: The HS subheading for chromium ore is HS subheading 2610.00. The HS subheading for ferrochromium is HS subheading 7202.41. (*) Both chromium ore and ferrochromium production data are published in quantity of metric tons. The model requires values, not quantities, so production quantities were converted to values with unit prices (AUVs). For Zimbabwe chromium ore, the AUV from the USGS minerals commodity surveys was used. For China chromium ore, a calculated export price from the UN Comtrade data was used. For Zimbabwe ferrochromium, it was assumed that all domestic production is exported because, according to industry resources, Zimbabwe was not known to have stainless steel production capacity, so export data is used to estimate ferrochromium domestic production.[62]

Finally, table 5 lists the elasticities used in the Zimbabwe model. The upstream elasticity of substitution parameter describes how ferrochromium producers substitute across available sources of chromium ore

[61] National Minerals Information Center, USGS, "Chromium Statistics and Information," accessed July 1, 2023.
[62] USGS, *Minerals Yearbook, Chromium*, 2018.

supply after a relative price change. The downstream elasticity of substitution parameter describes how downstream users (primarily stainless steel producers) substitute across available sources of ferrochromium supply after a relative price change. Both upstream and downstream elasticities were obtained from Soderbery (2018).[63] The price elasticities of supply parameters reflect the ability for chromium ore producers to increase chromium production following a price change and were chosen based on two factors: technological capabilities and capacity utilization.[64] For countries with less advanced technological capability, like Zimbabwe in 2011, a lower supply elasticity was chosen. If the country's production levels were near its total estimated reserves, a lower supply elasticity would also be chosen.[65]

Table 5 Elasticity parameter estimates used in Zimbabwe model

Elasticity parameter	Value	Source
Upstream elasticity of substitution	2.67	Soderbery (2018)
Downstream elasticity of substitution	2.83	Soderbery (2018)
Price elasticity of supply, Zimbabwe chromium ore production	3	Estimated
Price elasticity of supply, China chromium ore production	5	Estimated
Price elasticity of supply, ROW chromium ore production	5	Estimated
Price elasticity of supply, ROW ferrochromium production	5	Estimated

Economic Effects

Estimated economic effects of the Zimbabwe export ban are reported in table 6. The export ban is estimated to have decreased the price of Zimbabwean chromium ore by about 18.1 percent. Downstream domestic ferrochromium producers increased their purchasing of Zimbabwean chromium ore by about 14.7 percent. At the same time, total chromium ore production in Zimbabwe decreased (45 percent) as export destinations were no longer available to producers. This led to a price decrease for Zimbabwean ferrochromium (4.7 percent) and an increase in Zimbabwean ferrochromium quantity of production (15.2 percent) as more inputs were exclusively available and at a cheaper price, akin to a positive supply shift.[66] Chinese ferrochromium producers, on the other hand, experienced a modest decline in production quantities (less than one percent) as relatively less chromium ore inputs were available.

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[63] Soderbery, "Trade Elasticities, Heterogeneity, and Optimal Tariffs," September 2018.

[64] Because estimates of the price elasticity of supply for this industry and set of countries are not readily available in the literature, the estimates are chosen qualitatively based on information about production technology and capacity utilization. A value of 5 is considered an average elasticity, and a value of 3 is considered a low elasticity. Future research on this topic could quantitatively estimate these parameters.

[65] Zimbabwe has the second-largest high-grade chrome ore reserve base with total estimated reserves of 10 billion tons, or 12 percent of the global total. However, in 2019 Zimbabwe produced about one million tons of chromite, or 2.2 percent of the 44 million tons of chromite produced globally. Fastmarkets, "Industrial Minerals: Chrome and Chromite," accessed September 1, 2023.

[66] In dollar value terms, the model-estimated dollar value gain in Zimbabwe ferrochromium production was $19.12 million. The model-estimated dollar value loss in chromium ore exports was $60.23 million, greater than the gain in downstream production.

Table 6 Estimated economic effects of the 2011 Zimbabwe chromium ore export ban
In percent changes.

Variable	Estimated effect
Price of Zimbabwe chromium ore	-18.08
Quantity of Zimbabwe chromium ore sent to downstream Zimbabwe ferrochromium production	14.69
Quantity of total Zimbabwe chromium ore production	-45.03
Price of Zimbabwe ferrochromium	-4.65
Quantity of Zimbabwe ferrochromium	15.22
Price of Chinese ferrochromium	0.53
Quantity of Chinese ferrochromium production	-0.81

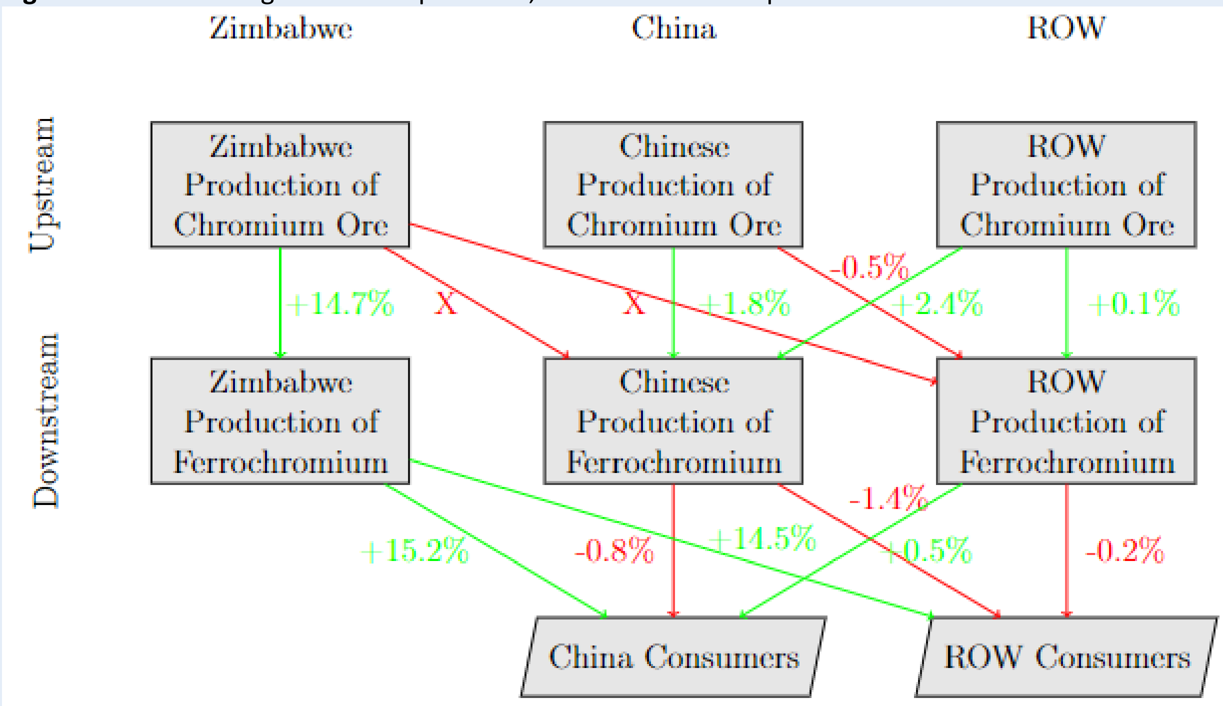
Source: Authors' estimates based on the modeling approach described above.
Note: The economic effects are in percent changes, calculated as the percent difference between actual market outcomes in 2010 and a counterfactual scenario where the export ban is in place.

Figure 5 shows the global reallocation of chromium ore and ferrochromium after the export ban was implemented in 2011. A red arrow reflects a reduction in traded quantities between two locations, and a green arrow reflects an increase in traded quantities between two locations. The red "X" symbols in the picture represent the export ban, with the trade flows reduced to zero. ROW consumers of ferrochromium include U.S. companies who use ferrochromium as inputs in stainless steel production.

These outcomes also illustrate that which supply chain segment is targeted by the restriction matters; closer supply chain connections are impacted more by a supply shock than industries farther removed from the targeted segment. As a result of the Zimbabwe export ban on chromium ore, the price of Zimbabwean chromium ore decreased by 18.1 percent. In the downstream ferrochromium segment, this translates to a 4.7 percent decrease in Zimbabwe ferrochromium prices, a 0.5 percent increase in Chinese ferrochromium prices, and a 0.1 percent increase in ROW ferrochromium prices. These price changes led to consumers of ferrochromium (primarily stainless steel producers) experiencing a negligible (0.04 percent) decrease in prices of ferrochromium used as inputs. Zooming out, the largest impacts of the restriction were felt by producers and consumers who interact with Zimbabwe directly, i.e. China.[67] In general, the greater the share of world trade covered by the export restriction, the greater the global distortion. Zimbabwe's share of the global supply of chromium ore was small at 1.9 percent of total production in 2010, so stainless steel producers in the rest of the world don't experience a large impact.

[67] The model shows that ferrochromium producers in China are negatively affected by the Zimbabwe export ban on chromium ore. However, Chinese ferrochromium producers that invest locally in Zimbabwe production facilities may also be benefitting from the export ban. The model does not measure changes in FDI and cross-border ownership.

Figure 5 Percent change in traded quantities, 2011 Zimbabwe export ban



Source: Authors' estimates based on the modeling approach described above.
Note: This figure shows the reallocation of chromium and ferrochromium trade after the export ban was implemented in 2011.

Comparing Modeled Outcomes with Actual Changes in the Data from 2011-2015

Next, a simple difference-in-differences (DID) regression model is run with a panel of global production data to compare modeled outcomes with actual changes in the data during the years of the export ban.[68] The methodology described in the modeling section above is useful for both prospective and retrospective analyses. With a prospective analysis, a researcher can model the future effects of implementing an export ban using the most recent year of data for the baseline. For a retrospective analysis, a researcher also has the benefit of comparing modeled outcomes to historical changes in the data. This DID regression can estimate the difference in trends in the data between Zimbabwe and all other countries that produce chromium ore. Modeled outcomes can then be compared with these differences in trends for Zimbabwe as additional information to understand the full set of impacts of an export ban.

The analysis uses a panel dataset of global chromium production (HS 2610.00) by country from 2008—2019, comprising the population of chromium producers worldwide.[69] The DID model estimates the average treatment effect (ATE) of Zimbabwe (the treated group) on production quantities during the period of the export ban (2011–2015). There are 22 countries in the control group, including three

[68] DID models can estimate the differential effect of exposure to a treatment (policy change) on a treatment group compared to a control group for a specified outcome.
[69] World Metal Statistics Yearbook 2022, World Bureau of Metal Statistics.

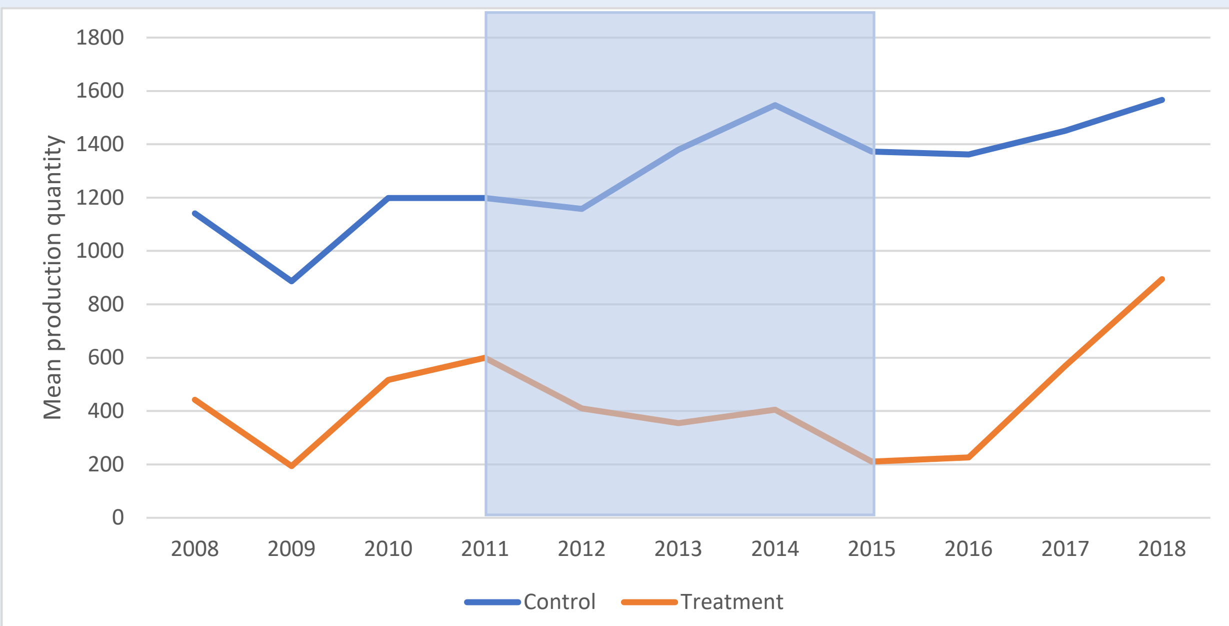
European countries, four African countries, twelve Asian countries, three countries in the Americas, and one Oceania country.[70]

The DID model can be written as follows. The variable y_{igt} is the quantity of chromium ore production by producing country, group, and year. The variable α_g and α_t are the group fixed effects and time fixed effects, respectively. D_{igt} is an indicator variable that equals one if in the treated group (Zimbabwe) and zero if in the control group. And the coefficient of interest is β, the average treatment effect of the treated group.

$$y_{igt} = \alpha_g + \alpha_t + \beta D_{igt} + \varepsilon_{igt}$$

The average treatment effect on Zimbabwe is -253.1. This means that the treated (Zimbabwe) had about 253,000 tons less in chrome production over the period of the export ban relative to the control group. In figure 6, there are parallel trajectories for the control and treated groups before the implementation of the export ban. During the ban years, from 2011–2015, Zimbabwe experienced a decline in chrome production levels compared to the control group. After 2015 when the export ban is removed, Zimbabwean production levels increased rapidly and eventually rose to the mean production level of the control group after 2019. This may suggest that it took time for Zimbabwean chromium ore producers to re-establish export relationships with trading partners after the export ban was removed, but ultimately rose above pre-2011 production levels.

Figure 6 Observed mean chromium ore production, treatment and control groups



Source: Authors' estimates based on the World Metal Statistics Yearbooks, World Bureau of Metal Statistics.
Note: The shading indicates the period of the Zimbabwe export ban. The treatment group is Zimbabwe, and the control group are the other 22 countries that produce chromium ore.

[70] The countries included in the DID are Afghanistan, Albania, Argentina, Australia, Brazil, China, Colombia, Finland, India, Iran, Japan, Kazakhstan, Madagascar, Oman, Pakistan, Philippines, Russia, South Africa, Sudan, Turkey, United Arab Emirates, Vietnam, and Zimbabwe.

The ATE estimated above can be compared with the simulated modeling results to understand how our estimates compare to the changes in historical data. Converting the ATE from quantity terms to value terms, the converted ATE is $89.85 million (253.1 thousand mt * $355/mt AUV). Next, the simulated annual change in Zimbabwean chromium production is calculated from the PE model. The estimated annual change in value from the implementation of the export ban is $60.23 million. This can be interpreted as the portion of the Zimbabwe decline in production that resulted from the export ban.

The model-produced number and the ATE are different because the model is based on an assumed counterfactual and the ATE is based on historical information. The modeled effect is an annual estimate that was estimated using only 2010 data, as if a researcher in 2010 wanted to estimate the impact of the impending export ban. The econometrics that produced the ATE is retrospective and compares trends in Zimbabwean production to the mean of the control group. They can be thought of as complementary analyses and used together to understand the impacts of the export ban on production. Further, the similarity in both direction and magnitude of outcomes from the two modeling approaches suggests that prospective analyses (as in the next section) will produce reasonable results.

Estimated Effects of the Zimbabwe Chromium Ore Export Ban in 2021

The model can similarly be applied to the Zimbabwe chromium ore export ban in 2021 and compare estimated effects with the estimated effects of the 2011 export ban. The model uses 2020 data to calibrate the baseline, applies the export ban to Zimbabwe chromium ore exports, and re-simulates a new market equilibrium set of prices and quantities with the export ban in place.[71] Elasticity estimates used in the model are the same as in the 2011 export ban analysis, except the Zimbabwe supply elasticity was revised upward (from 3 to 5) to reflect increased FDI by Chinese companies and improvements in technology. Economic effects are reported in table 7.

Table 7 Estimated economic effects of the 2021 Zimbabwe chromium ore export ban
In percent changes.

Variable	Estimated effect
Price of Zimbabwe chromium ore	-10.53
Quantity of Zimbabwe chromium ore sent to downstream Zimbabwe ferrochromium production	10.21
Quantity of total Zimbabwe chromium ore production	-42.67
Price of Zimbabwe ferrochromium	-4.96
Quantity of Zimbabwe ferrochromium	16.58
Price of Chinese ferrochromium	0.82
Quantity of Chinese ferrochromium production	-1.14

Source: Authors' estimates based on the modeling approach described above.
Note: The economic effects are in percent changes, calculated as the percent difference between actual market outcomes in 2020 and a counterfactual scenario where the export ban is in place.

[71] The most recent Zimbabwe export ban on HS subheading 2610.00 went into effect in 2021 for chromium ore and 2022 for chromium concentrates. Due to this staged entry into force, the model uses 2020, the year before the chromium ore ban was implemented, as the base-year of the analysis. The 2020 data inputs used in the model can be found in the modeling appendix (table A1).

Comparing tables 6 and 7, Zimbabwe ferrochromium producers are estimated to receive a greater benefit from the export ban in 2021 in terms of larger estimated percent increase in ferrochromium production—about 16.6 percent in 2021 compared to 14.7 percent in 2011. In addition, ferrochromium producers in China are estimated to experience a larger decline in production in 2021 (1.1 percent reduction compared to 0.8 percent reduction in 2011).

Several factors explain these differences. First, the estimated chromium ore cost share in Zimbabwe ferrochromium production has increased in recent years, so changes in the chromium industry have larger impacts on the ferrochromium industry. Second, Zimbabwe contributed a larger share of world chromium production in 2020, producing 4.5 percent of total world production compared to 1.9 percent in 2010. Coupled with the fact that Zimbabwe exports roughly 50 percent of its chromium ore production in non-ban years, the 2021 ban is estimated to have a larger impact on global chromium and ferrochromium trade relative to 2011.

Additionally, in the downstream, Zimbabwe ferrochromium export destinations are less diversified in 2020 compared to 2011. In 2020, China was the top export destination, receiving over 70 percent of Zimbabwe ferrochromium compared to about 25 percent in 2010. A larger negative upstream price change has a bigger impact on downstream Chinese producers importing chromium ore from Zimbabwe, leading to increased Zimbabwe ferrochromium purchases in China for stainless steel production.

Conclusion

As the first in a series on supply chain impacts from export restrictions on minerals and metals, this paper introduced background data and trends for global export restrictions from 2009-2021. Export bans as a share of total export restrictions introduced globally were highest in 2010 (26.2 percent), 2020 (22.5 percent), and 2021 (21.2 percent). Democratic Republic of the Congo, Indonesia, and Zimbabwe introduced 10 export bans on ores and concentrates from 2009-2021, including Zimbabwe's export ban on chromium ore.

A partial equilibrium model was used to estimate the impact of the Zimbabwe export bans on chromium ore, first introduced 2011-2015 and then reintroduced in 2021. The analysis found that the 2011 export ban on Zimbabwe chromium ore decreased the price of Zimbabwean chromium ore by about 18.1 percent. Downstream Zimbabwean ferrochromium producers increased their purchasing of Zimbabwean chromium ore by about 14.7 percent. At the same time, total chromium ore production in Zimbabwe decreased (45 percent) as export destinations were no longer available due to the ban. The estimated effects of the 2021 export ban are larger than those in 2011, in part because Zimbabwe's higher share of world chrome production in 2020 increased the impact of its export restrictions on the global supply chain. Overall, average world prices of ferrochromium (used primarily as inputs in stainless steel production) increased by a negligible 0.04 percent, illustrating that location of the policy in the supply chain and share of global supply matters.

Export restrictions are an important area for continued research as resource-rich, developing economies increasingly exercise export restrictions on raw materials inputs for high value downstream industries like EV batteries. The second paper in the series, *Export Restrictions on Minerals and Metals: Indonesia's*

Export Ban of Nickel, focuses on another example of a country that has implemented an export ban with the intention of boosting domestic production capacity.[72] The second paper provides a detailed look at the impact of Indonesia's recent nickel ore export ban on production, trade, and investment, while highlighting some of the challenges to Indonesia's nickel sector that have coincided with the trade policy.

[72] Guberman, Perry, and Schreiber, "Export Restrictions on Minerals and Metals: Indonesia's Export Ban of Nickel", 2024.

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Appendix

The table below lists data inputs used for the modeling analysis of Zimbabwe's 2021 export ban.

Table A1 Data inputs for Zimbabwe export ban model, 2020

Variable	2020 Value (millions of $)	Source
Production data*		
Zimbabwe chromium ore production value	$227.72	Estimated using the USGS world mineral statistics data and USGS minerals commodity surveys
China chromium ore production value	$0	USGS world mineral statistics
ROW chromium ore production value	$3,217.04	Estimated using the USGS world mineral statistics data and UN Comtrade data
Zimbabwe ferrochromium production value	$251.65	Estimated using the USGS minerals yearbooks and UN Comtrade data
China ferrochromium production value	$10,704.60	Estimated using the USGS minerals yearbooks and UN Comtrade data
ROW ferrochromium production value	$12,518.75	Estimated using the USGS minerals yearbooks and UN Comtrade data
Trade data		
China chromium ore imports from Zimbabwe	$108.13	UN Comtrade data
ROW chromium ore imports from Zimbabwe	$1.14	UN Comtrade data
China chromium ore imports from ROW	$1,936.16	UN Comtrade data
ROW chromium ore imports from China	$0	UN Comtrade data
China ferrochromium imports from Zimbabwe	$86.56	UN Comtrade data
ROW ferrochromium imports from Zimbabwe	$24.06	UN Comtrade data
ROW ferrochromium imports from China	$49.92	UN Comtrade data
China ferrochromium imports from ROW	$2,544.66	UN Comtrade data

Notes: The HTS code for chromium ore is HTS 2610. The HTS code for ferrochromium is HTS 720241. (*) Both chromium ore and ferrochromium production data are recorded in quantity of metric tons. The model requires values, not quantities, so production quantities were converted to values with unit prices (AUVs). For Zimbabwe chromium ore and ferrochromium, we used the AUV from the USGS minerals commodity surveys. For China ferrochromium, we used a calculated export price from the UN Comtrade data.