How Critical Are Critical Minerals? US Firm-Level Margins of Adjustment to China's 2010 Rare Earth Export Restriction*

Jaedo Choi
University of Texas at Austin

Razi Iqbal
University of Michigan

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Abstract

We study US firms' margins of adjustment to China's 2010 rare earth export restriction, using confidential firm-trade linked microdata. We use a difference-in-differences design, comparing rare earth importers with importers of other critical minerals. Although the supply disruption was temporary and prices normalized by 2015, rare earth importers suffered persistent declines in employment, revenues, and product variety through 2018. Their total exports remained stable. They dropped even products that rely little on rare earths. These findings suggest that firms revised their expectations about future policy risks and adjusted by narrowing product scope and concentrating scarce capabilities on core products.

Keywords: Critical minerals, global supply chain, export restriction
JEL Codes: F14, F51, F52

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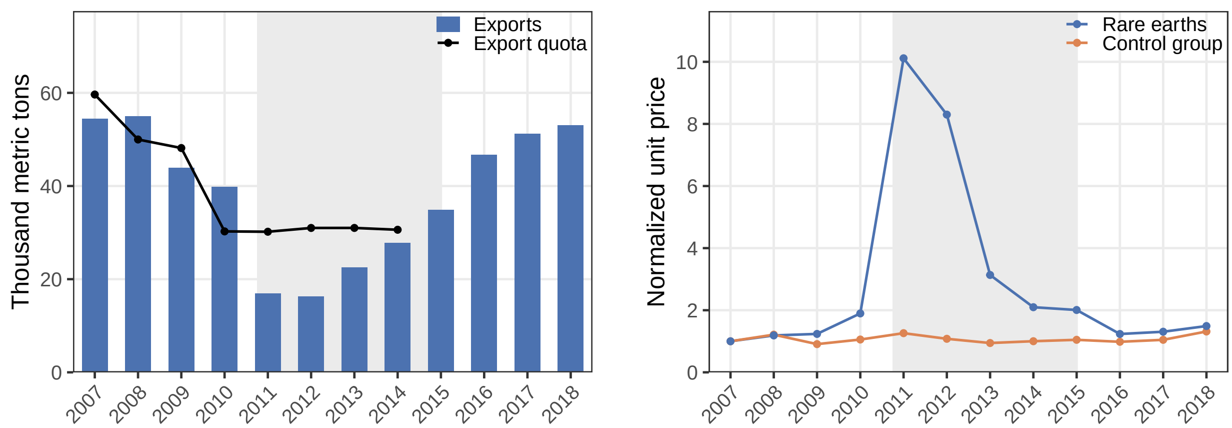
1. Introduction

Amid escalating geopolitical tensions, China imposed export restrictions on rare earths on April 4, 2025, in retaliation for the 34 percent tariffs that the US announced on April 2. Even before this action, US policymakers had expressed growing concerns because rare earths are key inputs for defense and high-tech industries, and China controlled roughly 60 percent of global mining and 90 percent of refining capacity as of 2023. However, there is limited evidence on how China's export restrictions on rare earths affect US firms.

Figure 1: China's 2010 Rare Earth Export Restriction as a Natural Experiment



A. China's Rare Earth Export Quota & Quantities Exported

B. US Average Import Prices of Rare Earths & Control Group Minerals

Notes. Panel A plots China's total rare earth export quantities and its export quota in gross weight, both obtained from USGS. Panel B plots the average US import prices of rare earths and control group critical minerals (cobalt, nickel, graphite, copper, lithium, tungsten, and molybdenum). The 2007 level is normalized to one for both groups. Import prices are computed as unit values obtained from Comtrade. In both panels, the shaded region denotes the restriction period, from October 2010 to January 2015. See Appendix A.1 for more details on the construction of this figure.

In this paper, we provide the first causal empirical evidence on US firms' margins of adjustment to China's rare earth export restrictions, using confidential firm-trade linked microdata. We use China's unexpected export restrictions on rare earths in 2010 as a natural experiment. Because the restriction was imposed in response to a territorial dispute with Japan over the Senkaku/Diaoyu Islands, it is unrelated to US-specific factors. The restriction led to global supply shortfalls and sharp price increases until China removed the export quota in 2015 following a World Trade Organization ruling (see Figure 1). This 2010 episode also raised concerns among Western policymakers that China could use such export restrictions as a geopolitical tool again.[1]

We use a difference-in-differences event study design to identify the impact of the rare earth restrictions on US firms. The treatment group consists of firms that imported rare earths at least once between 2007 and September 2010, one month before the territorial dispute occurred. The control group consists of US firms that imported any of seven other critical minerals—cobalt, nickel, graphite, copper, lithium, tungsten, and molybdenum—but not rare earths during the same time window. These control minerals were chosen based on reports from the US Geological Survey and International Energy Agency, which identify critical minerals based on China's dominance and their roles as key inputs to high-tech and energy-saving technologies. While rare earth prices rose to more than ten times their 2007 level after the episode, prices for the control minerals remained stable (Panel B of Figure 1).

We construct a firm-level panel by merging three confidential Census micro datasets: the Longitudinal Firm Trade Transactions Database, the Longitudinal Business Database, and the Census of Manufactures. We focus on manufacturing firms that use imported rare earths as inputs for production. The resulting dataset covers each manufacturing firm's product-level imports and exports, employment, revenues, and product mixes. We exploit the granular product-level trade information at the 8-digit HS code level to identify which firms import each critical mineral.

We present two main empirical findings. First, rare earth importers suffered persistent employment and revenue declines through 2018, even though China lifted its export quota and prices normalized by 2015. Employment and revenues of treated firms declined by 15 percent and 14 percent, respectively, in 2018 relative to control firms. Unlike employment and revenues, total exports did not experience such persistent declines. They dipped during the restriction period and then recovered.

Second, product variety fell along with employment and revenues and stayed lower. We document drops in both the number of products firms export, measured in the Longitudinal Firm Trade Transactions Database, and the overall number of products they produce, measured in the Census of Manufactures. Because total exports recovered by 2015 while the number of exported products stayed lower, exports per product rose. The decline in product variety was not confined to products that use rare earths intensively. The number of exported products fell by a similar magnitude among products that rely little on rare earths.

[1] Representative Donald A. Manzullo expressed concern at a hearing in September 2011: *"... The Chinese action sent a clear and unmistakable message to Japan and the rest of the world: China is willing to use economic tools to achieve diplomatic goals.. ... For America's defense industry, a total reliance on China for rare earth represents a serious weakness for national security. China currently controls 97 percent of the world's rare earth production.. ... "* (US House, 2011).

Simple back-of-the-envelope calculations based on our event study estimates imply that employment and revenue of treated firms were 80,000 and $42.2 billion (in 2010 dollars) lower per year, respectively, on average over the post-shock period (2011–2018).

The persistent declines in employment and revenues are difficult to explain by the cost shock alone. Rare earth prices reverted to their pre-shock level in 2015 and treated firms' rare earth imports recovered, yet employment and revenues were still depressed in 2018. A cost shock that works through contemporaneous input prices should have weakened once prices normalized, and the recovery in rare earth imports suggests that it had. Sunk costs of reintroducing products could make a temporary cost shock persistent, but only for products that use rare earths. However, firms also dropped products that rely little on rare earths. Thus, the cost shock is unlikely to explain the declines we observe afterward, even with sunk costs.

These results suggest that the episode shifted US firms' expectations about future policy risks, and that firms kept adjusting to them long after the disruption had ended, in part by narrowing product scope. Total exports were relatively stable while the number of exported products fell and exports per product rose. This indicates that firms kept their core products, which were competitive enough to be sold in global markets, and dropped the rest. Because the capabilities that support production, such as managerial attention, are scarce and shared across products within firms, protecting core products under a higher perceived risk of future restrictions likely came at the expense of marginal ones, including products that rely little on rare earths.

Related Literature. This paper contributes to the growing literature on the supply chain consequences of trade policies (e.g., Flaaen et al., 2020; Barattieri and Cacciatore, 2023; Flaaen and Pierce, 2024; Grossman et al., 2024b; Blanchard et al., 2025; Flaaen et al., 2025; Handley et al., 2025). While these papers study import tariffs, we study the effects of a foreign export restriction on downstream importers. Recent studies examine how firms diversify input sourcing under supply chain risk (e.g., Grossman et al., 2023, 2024a; Blaum et al., 2024; Castro-Vincenzi et al., 2025). Given China's near-monopoly, particularly in refining, US firms had little scope to diversify their rare earth sourcing. Instead, they adjusted the set of products they produce, the margin highlighted by the multiproduct firm literature (e.g., Bernard et al., 2011; Mayer et al., 2014; Arkolakis et al., 2021).

Cox (2026) finds persistent declines among downstream US manufacturers following the 2002 steel tariffs, and Lake and Liu (2025) document persistent effects of the same tariffs on local labor markets. Choi and Levchenko (2025) find persistent effects of South Korea's temporary industrial policy. Baldwin and Krugman (1989) and Dixit (1989) show that sunk costs can make the effects of temporary shocks persistent. In our setting, the persistent declines likely reflect firms' updated expectations about future policy risks (e.g., Pierce and Schott, 2016; Handley and Limão, 2017; Alessandria et al., 2025).

Ding et al. (2022) study the role of intangible capital in US manufacturing firms' contributions to non-manufacturing growth. Ding (2025) studies joint production in the presence of knowledge inputs. Our finding that product variety declined also suggests that production is similarly interdependent across products within firms. Almunia et al. (2021) show that a firm's domestic and export production are interdependent, finding that negative domestic demand shocks raise export flows. Our setting points to a related form of interdependence between domestic and export production, as a shock to imported input costs caused persistent declines in overall revenues but not in exports.

Finally, this paper relates to a growing literature on critical minerals. Domínguez-Iino et al. (2026) study how geopolitical risks in critical minerals affect the green transition, and Choi et al. (2026) study how China's strategic overproduction determines market structure in the rare earth refining sector. Relative to these papers, we provide causal evidence on US firms' margins of adjustment. Alfaro et al. (2025) study how the same 2010 episode affected directed innovation. Whereas they exploit sector-level variation in rare earth intensity, we exploit firm-level variation in direct imports of rare earths, which lets us trace how individual firms adjusted.

2. Background and Data

2.1 Background

In this section, we explain the background of China's 2010 export restriction, which we use as a natural experiment for our empirical analysis. Appendix A.2 provides more details on the background. In September 2010, China imposed export restrictions on rare earths following a diplomatic dispute with Japan over the Senkaku Islands (known as the Diaoyu Islands in China). The dispute began after the captain of a Chinese fishing trawler was arrested by the Japan Coast Guard near the islands, which strained relations between the two countries. Shortly thereafter, Chinese customs halted rare earth shipments to Japan and, in October, slowed shipments to the US and Europe. In October 2010, China officially cut the first round of its 2011 export quota by 35 percent, and it kept the annual quota at roughly 30,000 metric tons through 2014, down from roughly 48,000 metric tons in 2009. Although China officially cited environmental and resource-conservation concerns for the restriction, many observers believed that it was aimed at disrupting Japan's high-tech sectors, which depended heavily on rare earth supplies from China. The export quota applied to all importers. As a result, China's rare earth exports fell from 39,813 metric tons in 2010 to 16,900 metric tons in 2011, and the average US import price of rare earths in 2011 rose to roughly ten times their 2007 level.

In 2012, the US, the EU, and Japan filed complaints against the restriction with the WTO. China claimed that the export restriction could be justified under the WTO's GATT general exception clause Article XX, for the purpose of natural resource conservation and the protection of public health. However, the WTO found that the restriction violated international trade rules because it favored domestic firms and was not applied equally to domestic and foreign markets. This undermined the legitimacy of China's environmental justification. As a result, the WTO ruled against China, and China abolished the export quota with effect from January 1, 2015, and removed the remaining export duties on May 1, 2015.

Although the restriction was temporarily imposed from October 2010 to January 2015, this episode demonstrated that China could use rare earth export restrictions as an instrument of statecraft in the future, and heightened perceived geopolitical policy risk. This raised concerns among Western policymakers, given China's dominance in rare earth production. In 2010, China accounted for roughly 97 percent of global rare earth mining production and controlled 95 percent of global refining capacity (USGS, 2011).[2] By 2023, China's share of mining had fallen to 61 percent, but it still accounted for 92 percent of refining (Appendix Figure B.2).

The 2010 restriction thus caused short-run price spikes and led policymakers to revise upward their prior that similar episodes could recur in the future.

2.2 Data

Our main dataset comes from confidential Census Bureau datasets. The dataset is a firm-level panel spanning 2007 to 2018.[3] We restrict our sample to manufacturing firms (2-digit NAICS codes 31, 32, and 33).

The first main dataset is the Longitudinal Firm Trade Transactions Database (LFTTD), which links international trade transactions to individual firms (Bernard et al., 2009; Kamal and Ouyang, 2020). It records the universe of import shipments valued over $2,000 and export

[2] Critical minerals, including rare earths, generally require two stages before final use, mining and refining. Mining involves extracting and concentrating raw ore from the ground. Refining covers the chemical and metallurgical steps that transform those concentrates into market-ready chemicals, metals, or compounds.

[3] We use data up to 2018 to avoid the period when US-China trade tensions escalated and to exclude the impact of the pandemic.

shipments valued over $2,500 of merchandise goods, with information on the destination or source country, quantity, product code, and value of shipments at a monthly frequency. We aggregate these import and export transactions to the firm-year level.

Using the detailed product codes in the LFTTD, we can identify whether firms import rare earths or one of the seven control group minerals (tungsten, molybdenum, cobalt, nickel, graphite, copper, and lithium). Appendix Table B.2 reports the 8-digit HS codes for these critical minerals. The LFTTD reports HS codes at the 10-digit level, but we classify products at the 8-digit level for two reasons. First, all 10-digit codes within the rare earth 8-digit codes are rare earth products, so we do not lose any information by using the 8-digit level for our purpose. Second, the 10-digit codes were revised in 2013, 2014, and 2017, while the 8-digit codes in Appendix Table B.2 remained unchanged between 2007 and 2018. In the export data, we likewise define a product as an 8-digit HS code, and a firm's exported product variety in a given year as its number of distinct 8-digit HS codes.

The second main dataset is the Longitudinal Business Database (LBD), which provides information on firm outcomes. It includes annual information on employment, payroll, location, and industry affiliation for the universe of private non-farm establishments operating in the US, with firm identifiers (Jarmin and Miranda, 2002). We aggregate establishment-level outcomes to the firm level. We assign each firm a NAICS 5-digit code of the largest establishment it owns, and classify the corresponding firm as manufacturing based on this code. We keep only firms with positive employment. We also supplement the LBD with revenue data from tax records, constructed by Haltiwanger et al. (2016).[4]

We also use the US Census of Manufactures (CMF), which is conducted every five years, for 2007, 2012, and 2017. While the LBD annually covers the universe of establishments, both manufacturing and services, the CMF covers only manufacturing establishments and only every 5 years. We use the CMF to supplement our main LBD-based results. Its key advantage for our purposes is that it allows us to measure the number of unique products produced by each firm. For each establishment, we can observe 5-digit NAICS shipments, and we define the total number of product varieties as the number of distinct 5-digit NAICS codes across a firm's establishments and shipments in a given census year, the total-production counterpart to the count of exported products (8-digit HS codes) that we construct from the LFTTD.[5]

[4]Haltiwanger et al. (2016) describe in detail how they link the two datasets. The revenue data are sourced from the Census Bureau's Business Register and are based on administrative data from annual business income tax records. Overall, they match the two datasets for over 80 percent of observations in the LBD. Thus, revenues are missing for some firms. Although non-random missing could raise selection concerns, Haltiwanger et al. (2016) find that revenue missing is only weakly related to observable firm characteristics.

[5]Because concordances between 8-digit HS and 5-digit NAICS codes are imperfect, we define products separately in the LFTTD and the CMF rather than mapping one into the other.

3. Empirical Analysis

Using our merged dataset, we provide causal evidence on the impact of the 2010 rare earth restriction on US firms. Our design compares firms that were exposed to the restriction through their rare earth imports with otherwise similar firms that imported other critical minerals. We begin by defining the two groups.

Treatment and Control Groups. The treatment group consists of US firms that imported rare earths at least once between 2007 and September 2010, one month before the territorial dispute between China and Japan happened. The control group consists of firms that imported any of the seven control minerals (tungsten, molybdenum, cobalt, nickel, graphite, copper, and lithium) between 2007 and September 2010, but not rare earths.[6] If a firm imported both rare earths and control minerals, we classify it as a treated firm. We make this choice of control group based on reports from the US government and international energy organizations (US DOI, 2022; IEA, 2024). These reports identify these eight minerals as critical minerals, based on supply chain risks due to China's high market concentration, the size of their downstream sectors, and their importance for the green transition (e.g., batteries and electric vehicles). BRICS and G7 countries have similar lists of critical minerals (Evenett and Fritz, 2023).

There are three advantages to our research design. First, because the 2010 restriction arose from the unexpected diplomatic dispute between China and Japan rather than from China's relations with the US, it is arguably exogenous to US firms. Second, because the control minerals, like rare earths, are key inputs to high-tech or energy-saving sectors, they faced similar global demand shocks (see Appendix Table B.1 for detailed industrial uses of each mineral). Third, China holds large market shares in these minerals, especially in refining. Appendix Figure B.2 shows China's shares of global mining and refining for these minerals in 2023. China accounts for 61 percent of rare earth mining and an even larger share, 92 percent, of refining. Graphite shows a similar pattern. China accounts for 82 percent of its mining and 90 percent of its refining. For the other critical minerals, China's mining shares are smaller, ranging from less than 4 percent to 18 percent, but its refining shares are much

[6] China also imposed export quotas and duties on tungsten and molybdenum. The WTO ruling against China's rare earth export quota also covered the quotas on these two minerals. However, unlike for rare earths, China did not sharply cut quotas on them. The tungsten quota fell slightly from 17,200 metric tons in 2007 to 15,400 metric tons in 2012 and stayed there until 2014, and the molybdenum quota stayed at about 25,000 tons between 2010 and 2013, both in metal content (Panel A of Appendix Figure B.3). US import prices of tungsten stayed around their 2007 level and those of molybdenum stayed below it, while rare earth prices rose about tenfold (Panel B). If control firms were also affected, our estimates would be biased toward zero.

Table 1: Descriptive Statistics: Treated and Control Firms in 2010

Variables	Treated firms	Control firms
Avg. employment	4,293	1,841
Avg. wage (2010 USD)	75,480	72,760
Share of exporters (%)	98	94
Avg. rare earth imports (metric ton)	19	0
Avg. control mineral imports (metric ton)	151	232
Avg. revenue (million USD)	2,229	1,478
Avg. exports (million USD)	549	230
Number of unique firms	150	500

Notes. This table reports descriptive statistics of the treated and control firms in 2010. The sample includes only manufacturing firms. Treated firms are those that imported rare earths between 2007 and September 2010. Control firms are those that imported any of tungsten, molybdenum, cobalt, nickel, graphite, copper, and lithium during the same time window, but not rare earths. Observation counts are rounded in accordance with Census disclosure requirements.

larger, ranging from 27 percent to 79 percent.[7]

The identifying assumptions are that the treated and control groups would have followed parallel trends in the absence of the restriction and that the 2010 restriction is exogenous to US firms. The event study below allows us to check pre-trends directly. One concern is that we cannot observe domestic transactions, because the LFTTD covers only international trade. Firms in the control group may purchase rare earths indirectly from domestic wholesalers or retailers, and we cannot account for such purchases. However, such indirect exposure would narrow the post-restriction gap between the two groups, so our estimates are likely lower bounds on the magnitude of the true effects.

Table 1 reports the descriptive statistics of the treated and control firms in 2010. Our sample includes only manufacturing firms, with 150 treated firms and 500 control firms. Treated firms tended to have larger employment, revenues, and exports than the control firms, but they had similar levels of average wage (wage bills divided by total employment) and exporter shares. The average treated firm imported 19 metric tons of rare earths.[8] Total imports of critical minerals in metric tons (the sum of rare earths and control minerals) were broadly comparable across the two groups, at 170 metric tons for the treated group and 232

[7]China accounts for 18 percent of lithium mining but 65 percent of lithium refining, 8 percent of copper mining but 44 percent of copper refining, and less than 4 percent of cobalt and nickel mining but 79 and 27 percent of their refining, respectively. The IEA data underlying Appendix Figure B.2 do not cover tungsten and molybdenum.

[8]Our sample includes only firms whose largest establishment is in manufacturing. The 150 treated manufacturers accounted for roughly 25 percent of total US rare earth imports in 2010. They imported an average of 19 metric tons, compared with 38 metric tons across all 300 firms that imported rare earths, including non-manufacturing firms. See Appendix Table B.3 for descriptive statistics on all firms that imported rare earths.

for the control group.

Event Study Specification for the LBD Sample. Using the constructed treatment and control groups, we estimate the following event study specification:

$$y_{ft} = \sum_{\tau=2007}^{2018} \beta_\tau \left(\text{Treated}_f \times D_\tau\right) + \gamma_f + \delta_{jt} + \varepsilon_{ft}, \tag{3.1}$$

where f denotes firm and t calendar year. Treated_f is an indicator for treatment status and equals one if firm f is in the treated group. $D_\tau := \mathbb{1}[t = \tau]$ are the event study variables, which equal one when the calendar year t equals τ. We normalize $\beta_{2010} = 0$, so all coefficients are measured relative to 2010. γ_f are firm fixed effects and δ_{jt} are NAICS 2-digit-by-year fixed effects. ε_{ft} is the error term. Standard errors are clustered at the firm level.

For dependent variables with many zeros (e.g., exports and imports), we consider the analogous Poisson pseudo-maximum likelihood (PPML) specification (Santos Silva and Tenreyro, 2006):

$$y_{ft} = \exp\left(\sum_{\tau=2007}^{2018} \beta_\tau \left(\text{Treated}_f \times D_\tau\right) + \gamma_f + \delta_{jt} + \varepsilon_{ft}\right). \tag{3.2}$$

The event study coefficients β_τ in equations (3.1) and (3.2) allow us to track the dynamic effects of the export restriction and to examine pre-trends.[9]

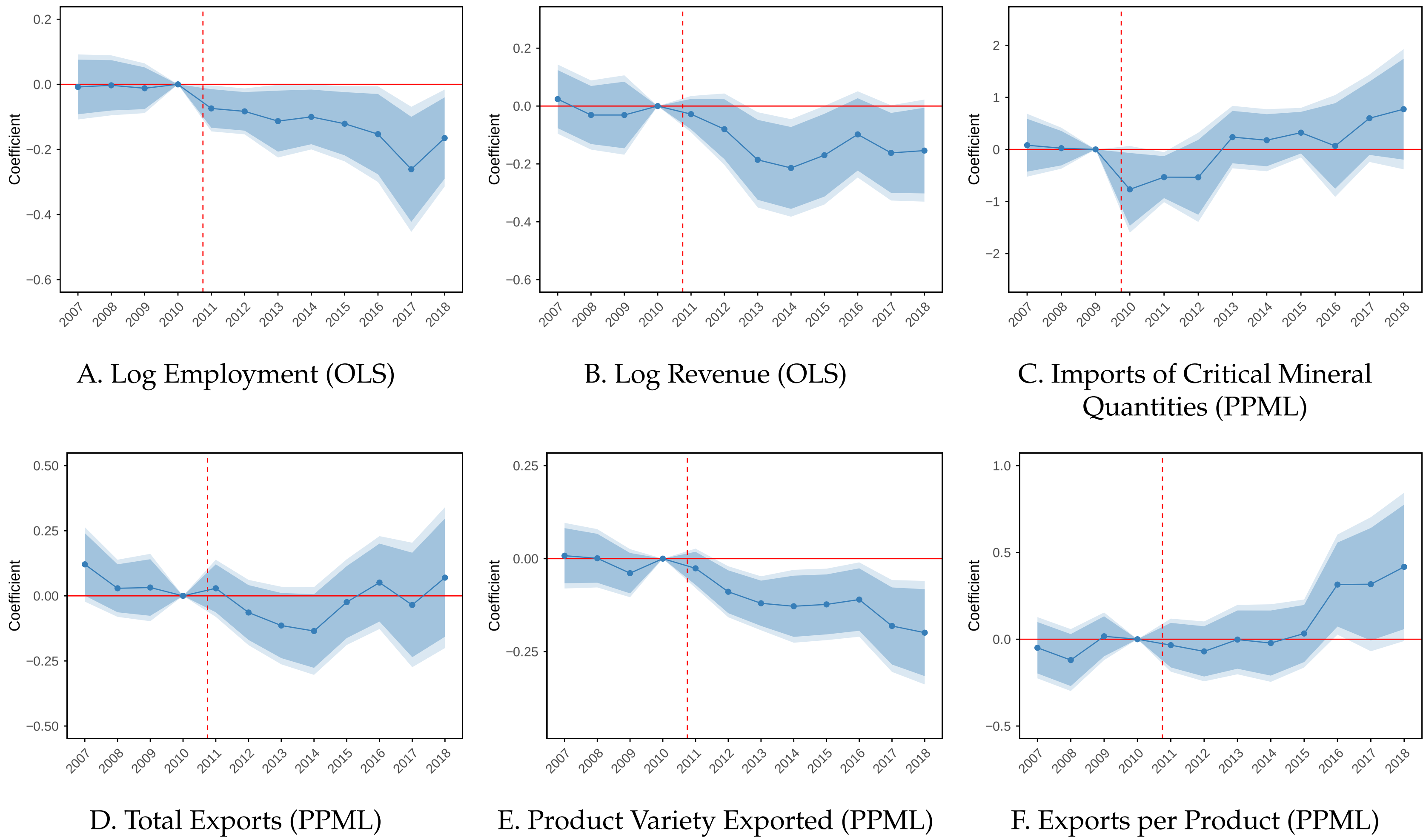
Panels A and B of Figure 2 report the estimation results for employment and revenues. Although China removed its export quota in 2015 and rare earth prices had come down drastically from their 2011 peak by that year, treated firms suffered persistent declines in both outcomes. In 2012, two years after the restriction, treated firms' employment had dropped by 8 percent relative to control firms. The gap widened in later years, and in 2018, eight years after the restriction, their employment was still 15 percent lower. Revenues followed a similar pattern and remained about 14 percent lower in 2018 relative to control firms.

In Panel C, the outcome is imported quantities of critical minerals in gross weight: rare earths for treated firms and the seven control minerals combined for control firms.[10] For this outcome, we normalize the 2009 coefficient rather than the 2010 coefficient to zero ($\beta_{2009} = 0$). Shipments were restricted from October 2010, and we construct yearly firm-level imports as the sum of each firm's monthly import flows, so annual imports in 2010 already partly

[9] Because the shock occurred for all firms in 2011, we do not face the issues associated with the recent staggered difference-in-differences literature (e.g., Roth et al., 2023).

[10] We use imported quantities in metric tons rather than import values because prices rose to about ten times their 2007 level during the restriction period (Panel B of Figure 1), so estimates for import values turn positive. US import values of rare earths from China in the Comtrade data rose over this period as well (Panel B of Appendix Figure B.1).

Figure 2: Event Study: The Impact of China's 2010 Rare Earth Export Restriction on US Firm Outcomes



Notes. This figure reports the estimated coefficients of equations (3.1) and (3.2) with 90% and 95% confidence intervals based on standard errors clustered at the firm level. Panels A and B are estimated by OLS and Panels C through F by PPML. The dependent variables are log employment (Panel A), log revenue (Panel B), imported quantities of critical minerals (Panel C), total exports (Panel D), the number of unique products exported (Panel E), and exports per product (Panel F). In Panel C, the dependent variable is imports of rare earths in metric tons for treated firms and the sum of imports of the control minerals in metric tons for control firms. β_{2010} is normalized to zero in all panels except Panel C, where β_{2009} is normalized to zero because shipments were restricted from October 2010 and imports are calculated as the sum of monthly import flows in a given year. The sample consists of manufacturing firms from the LBD. All specifications include firm and NAICS 2-digit-by-year fixed effects.

reflect the shock. Employment and revenues are annual LBD measures, so for them we keep $\beta_{2010} = 0$.[11] Treated firms' imported rare earth quantities fell relative to control firms, by about 41 percent to 54 percent between 2010 and 2012, but returned to their pre-shock level thereafter.[12] Access to rare earths thus recovered after 2012, while employment and revenues remained lower.

Panels D through F of Figure 2 report the estimation results for export outcomes. Total exports dipped between 2012 and 2014 and recovered thereafter, and the coefficients are not statistically distinguishable from zero in any year (Panel D). While total exports returned to their pre-shock level, treated firms changed the composition of their export baskets. The number of unique products they exported fell persistently (Panel E). Exports per product stayed close to their pre-shock level through 2015, as total exports and the number of exported products fell together (Panel F). Once total exports recovered in 2015 while the number of exported products stayed low, exports per product rose, by about 37 percent in 2016 and 52 percent in 2018. Using the CMF, we show below that these compositional changes occurred not only in the products treated firms export, but also in the overall products they produce.

We define six broad product categories following Freund et al. (2024): electrical equipment, machinery, metals, mineral products and chemicals, transportation equipment, and other products. The first five consist largely of products linked to national security and high-tech applications, which include the main uses of rare earths, such as permanent magnets, catalysts, and glass and ceramics (Appendix Table B.1). The last is the residual category. Based on this classification, we count the number of products each firm exports in each category. If the restriction had worked only through the cost of rare earths, treated firms would have dropped the products that use rare earths most intensively, and the decline would be concentrated in the first five categories.

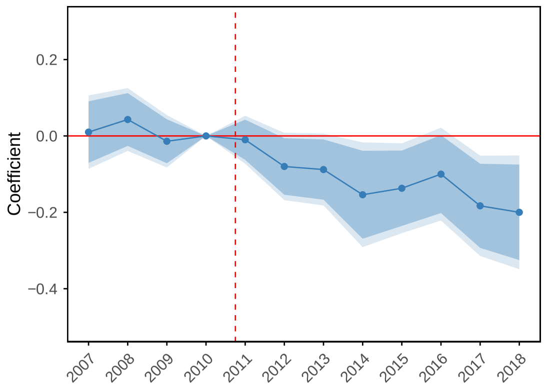
Figure 3 shows that this is not the case. The number of exported products in the residual category (Panel F) shows no pre-trend, falls in every year from 2012, and by 2018 is about 17 percent lower, similar to the declines in machinery and electrical equipment. The declines are less precisely estimated for mineral products and chemicals and for transportation equipment, which also shows a significant positive coefficient in 2009. Treated firms thus dropped even products that rely little on rare earths.

Using the estimates in Figure 2, we conduct a simple back-of-the-envelope calculation of

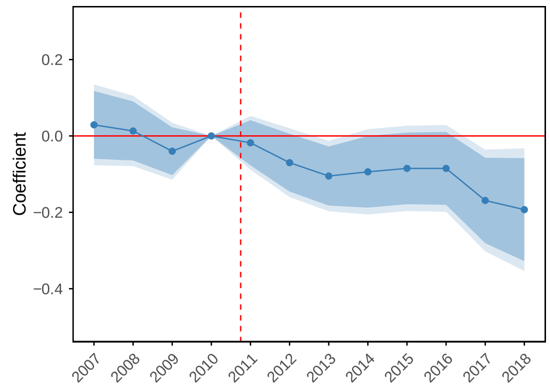
[11] In the LBD, employment is measured in the pay period including March 12 of each year, so the 2010 coefficient for employment does not reflect the shock. Revenues are the receipts reported on annual business income tax returns for the tax year, so the 2010 coefficient could partly absorb it. We normalize the 2010 coefficient to zero for both outcomes for consistency, and revenues show no decline in 2010 relative to 2009.

[12] In the Comtrade data, aggregate US imports of rare earths from China also returned to roughly their 2009–2010 level by 2016 (Panel A of Appendix Figure B.1), so the recovery is not only relative to control firms.

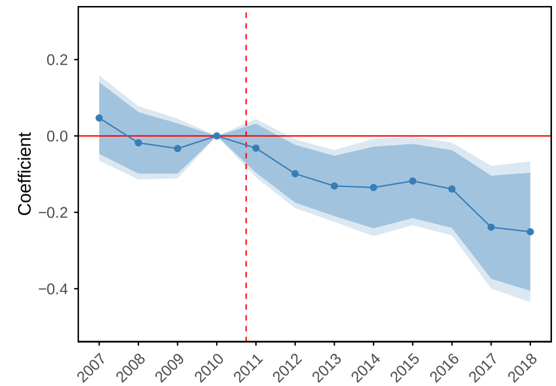
Figure 3: Event Study: Product Variety Exported by Category



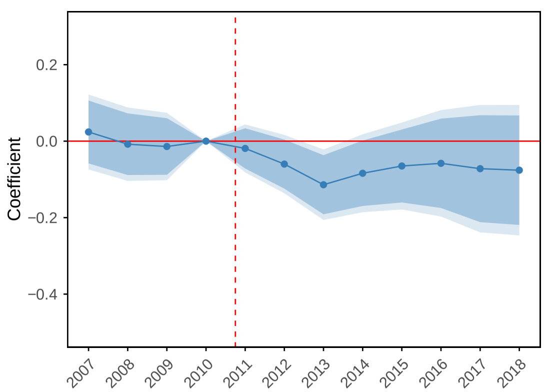
A. Electrical Equipment



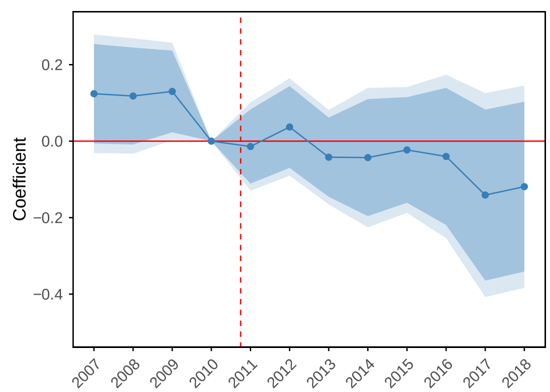
B. Machinery



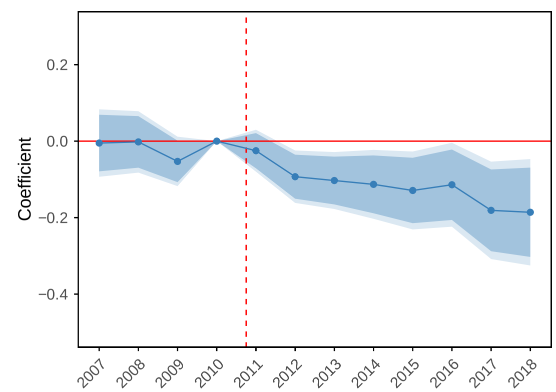
C. Metals



D. Mineral Products and Chemicals



E. Transportation Equipment



F. Other Products

Notes. This figure plots the estimated coefficients of equation (3.2) for six categories of exports, with 90% and 95% confidence intervals based on standard errors clustered at the firm level. The dependent variable is the number of unique products exported by the firm in that category. The 2010 coefficient β_{2010} is normalized to zero. All specifications include firm and NAICS 2-digit-by-year fixed effects.

Table 2: Long-Difference Specification: The Impact of China's 2010 Rare Earth Export Restriction on US Firm Outcomes

	Panel A. Dep. Var.: Outcomes over 2007–2012						
	Employment	Revenue	Exports	Product Variety	Total Assets	Material Costs	Production Workers
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated_f	-0.089	-0.098	-0.208	-0.146	-0.184	-0.093	-0.100
	(0.054)	(0.085)	(0.134)	(0.054)	(0.075)	(0.106)	(0.062)
Num. Obs.	550	550	350	550	550	550	550

	Panel B. Dep. Var.: Outcomes over 2007–2017						
	Employment	Revenue	Exports	Product Variety	Total Assets	Material Costs	Production Workers
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated_f	-0.140	-0.180	0.006	-0.145	-0.185	-0.132	-0.094
	(0.097)	(0.119)	(0.190)	(0.076)	(0.109)	(0.141)	(0.102)
Num. Obs.	450	450	300	450	450	450	450

Notes. Standard errors clustered at the firm level are reported in parentheses. This table reports estimates of β from equation (3.3). The dependent variable is the change in the log of the indicated outcome between 2007 and 2012 in Panel A and between 2007 and 2017 in Panel B. Material costs are the cost of materials and parts. The sample consists of manufacturing firms in the CMF. The sample size drops for export outcomes because of zeros and the log transformation, and missing information. All specifications include NAICS 2-digit fixed effects. Observation counts are rounded in accordance with Census disclosure requirements.

the impact of the rare earth shock on US employment and revenues. In 2010, total employment in treated firms was 644,000, while total revenue of treated firms was $334.4 billion (in 2010 dollars). We multiply total employment and revenue by the corresponding $(e^{\beta_\tau} - 1)$, with β_τ the relevant coefficient for each year, to get the impact of the shock on employment and revenue in that year. We then average across years to get the average annual effect in the post-treatment period (2011–2018). Scaling the estimated treatment effects by the total employment and revenue of treated firms in 2010, we find that in the average post-shock year, employment and revenue were approximately 80,000 and $42.2 billion (in 2010 dollars) lower than they would have been without China's export restriction. We view this as a conservative estimate of the total impact of the rare earth shock, because our sample does not account for firms that purchase rare earths from domestic retailers and wholesalers and this calculation does not account for the propagation of the shock through input-output linkages.[13]

[13] Our treated firms accounted for roughly 25 percent of total US rare earth imports. In other words, 75 percent of rare earths were imported by firms whose largest plant is non-manufacturing.

Long-Difference Specification for the CMF Sample. We supplement the baseline results with the CMF sample for two reasons. First, the CMF reports each establishment's 5-digit NAICS code, so we can measure the number of products a firm produces as the number of unique codes across its establishments. With this information, we can examine whether the decrease in the number of products, reported in Panel E of Figure 2, is confined to exports or extends to overall production. Second, the CMF has additional firm-level variables, not available in the LBD.

We consider the following long-difference specification for the 2007–2012 and 2007–2017 periods, which aligns with the time frame of our event study analysis:

$$\Delta \log y_f = \beta \text{Treated}_f + \delta_j + \varepsilon_f, \tag{3.3}$$

where $\Delta \log y_f$ denotes the time difference in the log of firm outcomes for either 2007–2012 or 2007–2017. δ_j denotes NAICS 2-digit fixed effects. ε_f is the error term. Standard errors are clustered at the firm level. Compared to the event study, the sample size becomes smaller for the long-difference specification as we require firms to operate in both 2007 and 2012, or 2007 and 2017.

Table 2 reports the estimation results using the CMF data. The estimates are quantitatively and qualitatively similar to the event study estimates. Employment and revenue (columns 1 and 2) declined in the midst of the restriction in 2012 and remained lower in 2017, even after the quota was lifted. Exports in column 3 declined by 2012 but recovered to the pre-shock level by 2017. We also find a persistent decline in the total number of product varieties (column 4), which remains in 2017. This shows that the decline in exported product variety in the LBD event study extends to total product variety, including products that may also be sold domestically.

We also examine three variables we do not observe in the LBD (total assets, material costs, and production workers), reported in columns 5, 6, and 7, respectively. Total assets decline persistently and significantly at both horizons. Material costs decline as well, but by less, and imprecisely. We examine production workers to test whether firms systematically changed their production structure. The estimates are similar in magnitude to those for total employment, within one standard error at both horizons.

We also estimate the long-difference specification weighting by initial employment in 2007 (Appendix Table B.4). We find that the declines are larger in magnitude under weighting, beyond one standard error of the unweighted estimates and by factors ranging from roughly

2 to 9. This suggests that larger firms tended to respond more.[14] We also report estimates that omit the industry fixed effects (Appendix Table B.5). The estimates are nearly identical to the baseline, indicating that the results are unlikely to be driven by industry composition.

4. Discussion

The declines in employment and revenues show that the effects of export restrictions can outlast the short-term price spikes. This persistence is hard to reconcile with standard static trade models, in which substitution depends only on current input costs (e.g., Costinot and Rodríguez-Clare, 2014). Instead, China's dominance in rare earths and the risk of future export controls likely led US importers to expect further disruptions and to change their product mixes. Evaluating such policies therefore requires accounting for expectations (Alessandria et al., 2025) and uncertainty (Pierce and Schott, 2016; Handley and Limão, 2017) about future policy risk.

The declines in product variety show that firms responded to geopolitical risk by changing their product mixes. Treated firms narrowed their product lines while keeping total exports relatively stable, even as revenue and employment fell. This suggests that they kept the core products that could compete in global markets and dropped marginal ones. The literature on multiproduct firms shows that firms adjust their product scope to market conditions (e.g., Bernard et al., 2011; Mayer et al., 2014; Arkolakis et al., 2021). We show that they adjust along a similar margin in response to input supply risk.

The set of products that firms dropped suggests interdependence across products. In standard multiproduct firm models, production and export decisions are separable across products conditional on firm productivity (e.g., Bernard et al., 2011), so a rare earth cost shock would lead firms to drop mainly the products that use rare earths intensively, even with product-specific sunk costs. Instead, the number of exported products fell as much in the residual category as in machinery and electrical equipment (Panel F of Figure 3), while rare earth imports recovered. This pattern is consistent with firms concentrating scarce capabilities on their core products when a critical input became risky, and with joint production through intangible capital or non-rival inputs, as Ding et al. (2022) and Ding (2025) document for US firms.[15]

[14] Heterogeneity in effects is one source of the divergence between the unweighted and weighted estimates. As Solon et al. (2015) note, when effects are larger in larger units, weighting tends to produce larger estimates.

[15] Appendix C presents a simple model that rationalizes these findings. An entrepreneur allocates limited capability between reducing the policy risk of the core product and improving the quality of non-core products, which are not exposed to that risk. When risk rises, the entrepreneur shifts capability toward the core product, so non-core revenues fall on both the intensive and extensive margins, and exports per product rise as the core

Finally, although the perceived risk of further restrictions rose, firms' rare earth imports returned to pre-shock levels (Panel C of Figure 2). This highlights how hard it is to substitute away from rare earths or to diversify supply under China's near-monopoly, particularly in refining, where China still accounted for 92 percent of global capacity in 2023 (Appendix Figure B.2; Choi et al., 2026). Firms instead adjusted in other ways, such as their product mix, as we document, or innovation that substitutes away from rare earth inputs (Alfaro et al., 2025). Policies that make such substitution easier can strengthen firms' resilience to future restrictions.

5. Conclusion

Using confidential US microdata linking firms to their trade transactions, we provide the first firm-level evidence on US firms' margins of adjustment to China's 2010 rare earth export restriction. The disruption was temporary. China lifted the restriction in 2015, import prices returned to pre-shock levels, and treated firms' mineral imports recovered. However, the restriction persistently lowered firm employment and revenues, which remained below pre-shock values.

These results are consistent with firms revising their expectations about future policy risk and, in response, focusing on their core products and dropping non-core products. The declines in product variety indicate that production is interdependent across products within firms. Rare earth imports returned to their pre-shock level after 2012, even though perceived geopolitical risk had risen. This also suggests that it is hard to substitute away from rare earths. Understanding how firms adjust matters for evaluating foreign export restrictions and for making the US economy more resilient amid geopolitical tensions.

product accounts for a larger share of exports.

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ONLINE APPENDIX
(NOT FOR PUBLICATION)

A. Background

A.1 Data Construction for Figure 1

Both series in Panel A are measured in metric tons of gross weight of rare earth products. Export quantities for 2008 through 2018 are obtained from China Customs figures, reported in the USGS Minerals Yearbook, volume III, *The Mineral Industry of China*, table 3 ("Exports of selected mineral commodities") (U.S. Geological Survey, 2008–2019). The 2017–18 and 2019 editions report the same value for 2018. The 2007 value is taken from the rare earths chapter of the same yearbook (U.S. Geological Survey, 2007–2013a, 2007 edition).

Export quotas for 2007 through 2010 are obtained from table 1 of Tse (2011). Quotas for 2011 through 2013 are taken from the USGS Minerals Yearbook China chapters (U.S. Geological Survey, 2008–2019, 2011–2013 edition) and the USGS yearbook reports 30,999 tons (U.S. Geological Survey, 2007–2013a, 2013 edition). China abolished the quota on January 1, 2015 (U.S. Geological Survey, 2008–2019, 2014 edition), and removed the remaining export duties on May 1, 2015 (Customs Tariff Commission of the State Council, 2015). The quota series therefore ends in 2014.

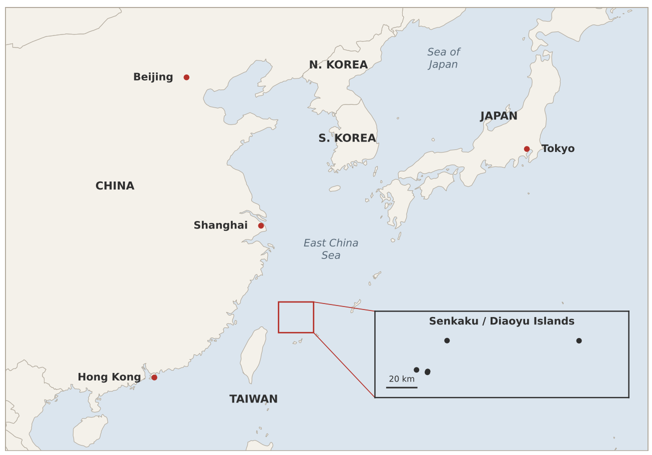
Panel B reports average US import unit values for rare earths and for the seven control group minerals. We aggregate Comtrade records of US imports from the world to the annual level across the HS codes reported in Table B.2, divide total import value by total net weight within each group, and normalize the resulting unit value to one in 2007. Where net weight is missing for a code in a given year, we impute it using the growth rate of reported quantities for the codes in the same group with complete data.

Figure B.1 reports quantities and values imported from China by the US, Japan, and the rest of the world, constructed from the bilateral Comtrade data. These quantities exceed the quota in every year. The gap arises because the 6-digit HS basket is broader than the set of products the quota covered.

A.2 Dispute between China and Japan over the Senkaku/Diaoyu Islands

The Senkaku Islands (Diaoyu in China) were a source of tension between China and Japan long before 2010. See Figure A.1 for their locations. Japan incorporated the islands into Okinawa Prefecture in January 1895 and administered them until 1945. The US governed Okinawa, including the Senkaku Islands, from 1945 until returning them to Japan. China has asserted historical sovereignty based on Qing-era records, and tensions first emerged in the 1970s after a 1969 UN survey indicated potential oil and gas resources in the area (Green et al., 2017).

Figure A.1: Senkaku/Diaoyu Islands



On September 7, 2010, the Chinese trawler entered waters claimed by Japan near the Senkaku Islands and ignored orders from the Japan Coast Guard vessels. The Coast Guard arrested the Chinese trawler's captain. The Chinese government demanded his unconditional release and suspended diplomatic meetings with Tokyo. The captain was held for 17 days and released without trial on September 24, and Japan cited diplomatic and political considerations in its decision (Green et al., 2017).

On December 28, 2010, the Ministry of Commerce officially announced an initial 2011 export quota of 14,446 metric tons, 35 percent below the corresponding announcement a year earlier (Tse, 2011). A further allocation in July 2011 (Ministry of Commerce of the People's Republic of China, 2011) raised the annual quota to 30,184 metric tons (Morrison and Tang, 2012). In March 2012, Japan, the US, and the EU jointly requested WTO consultations against China's export restrictions on rare earths. The WTO concluded that China's measures violated GATT Article XI as well as China's WTO accession commitments. It rejected China's conservation defense on the grounds that domestic consumers were not similarly restricted (World Trade Organization, 2014). China abolished its export quotas with effect from January 1, 2015 (U.S. Geological Survey, 2008–2019, 2014 edition).

B. Additional Tables and Figures

B.1 Additional Tables

Table B.1: Selected Industrial Uses of Treated and Control Group Critical Minerals

Critical minerals	Industrial use
Rare earths	Catalysts (petroleum refining, automotive), permanent magnets (EV motors, wind turbines), ceramics and glass, polishing materials
Tungsten	Carbide tooling (construction, mining, drilling), alloys and specialty steels, electrical components (electrodes, filaments), chemical catalysts
Nickel	Stainless steel, superalloys (aerospace, turbines), electroplating, chemical catalysts
Copper	Electrical wiring and power cables, construction (plumbing, roofing), industrial machinery, brass and bronze alloys
Cobalt	Superalloys (aircraft engines), battery cathodes (Li-ion batteries), chemical catalysts, carbide tools
Molybdenum	Alloying agent (structural steels, superalloys), chemicals (catalysts, lubricants, pigments), high-temperature refractories
Lithium	Rechargeable batteries (EV, electronics), ceramics and glass flux, lubricating greases, metallurgical fluxes (aluminum casting)
Graphite	Battery anodes, fuel cells, high-temperature lubricants, brake linings, refractories, steelmaking electrodes

Notes. This table reports industrial uses of treated and control group critical minerals. The information is obtained from U.S. Geological Survey (2024).

Table B.2: Critical Mineral 8-digit HS Codes

Critical minerals	Treated/control	8-digit HS codes							
Rare earths	Treated	2846.90.20	2846.90.40	2846.90.80	2805.30.00	2846.10.00	3606.90.30	2612.20.00	
Tungsten		2611.00.30	2611.00.60	2620.99.20	2841.80.00	2825.90.30	2827.39.40	2849.90.30	2850.00.10
Molybdenum		2613.10.00	2613.90.00	2825.70.00	2841.70.10	2841.70.50	3815.90.20		
Cobalt		2605.00.00	2822.00.00	2827.39.60	2833.29.10	2836.99.10	2915.29.30		
Nickel	Control	2604.00.00	2825.40.00	2827.35.00	2833.24.00	3815.11.00			
Graphite		2504.10.10	2504.10.50	2504.90.00	3801.10.10	3801.10.50	3801.20.00	3801.30.00	3801.90.00
Copper		2603.00.00	2825.50.10	2825.50.20	2825.50.30	2827.41.00	2833.25.00	2827.60.10	
Lithium		2805.19.90	2825.20.00	2836.91.00	2826.90.90				

Notes. This table presents the 8-digit HS codes we use to identify US firms importing particular critical minerals. All codes are in effect throughout 2007–2018.

Table B.3: Descriptive Statistics: Treated and Control Firms in 2010 (including non-manufacturing firms)

Variables	Treated firms	Control firms
Avg. employment	6,867	3,078
Avg. wage (2010 USD)	59,000	64,140
Share of exporters (%)	90	82
Number of firms	300	1,000
Avg. Rare earth imports (metric ton)	38	0
Avg. Control mineral imports (metric ton)	97	188
Avg. Revenue (million USD)	3,107	1,872
Avg. exports (million USD)	389	229

Notes. This table reports descriptive statistics of the treated and control firms in 2010. Sample includes both manufacturing and non-manufacturing firms. Treated firms are those that imported rare earths between 2007 and September 2010. Control firms are those that imported any of Tungsten, Molybdenum, Cobalt, Nickel, Graphite, Copper, and Lithium during the same time window.

Table B.4: Robustness: Long-Difference Estimates Weighted by Initial Employment

	Panel A. Dep. Var.: Outcomes over 2007–2012						
	Employment	Revenue	Exports	Product Variety	Total Assets	Material Costs	Production Workers
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated$_f$	-0.271	-0.699	-0.436	-0.318	-0.331	-0.320	-0.307
	(0.124)	(0.537)	(0.225)	(0.155)	(0.155)	(0.201)	(0.126)
Num. Obs.	550	550	350	550	550	550	550

	Panel B. Dep. Var.: Outcomes over 2007–2017						
	Employment	Revenue	Exports	Product Variety	Total Assets	Material Costs	Production Workers
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated$_f$	-0.797	-1.148	-0.537	-0.541	-0.575	-0.804	-0.859
	(0.461)	(0.691)	(0.238)	(0.311)	(0.279)	(0.472)	(0.465)
Num. Obs.	450	450	300	450	450	450	450

Notes. Standard errors clustered at the firm level are reported in parentheses. This table reports estimates of β from equation (3.3), weighting each firm by its employment in 2007. The specification is otherwise identical to Table 2. The dependent variable is the change in the log of the indicated outcome between 2007 and 2012 in Panel A and between 2007 and 2017 in Panel B. Material costs are the cost of materials and parts. The sample consists of manufacturing firms in the CMF. The sample size drops for export outcomes because of zeros and the log transformation, and missing information. All specifications include NAICS 2-digit fixed effects. Observation counts are rounded in accordance with Census disclosure requirements.

Table B.5: Robustness: Long-Difference Estimates without Industry Fixed Effects

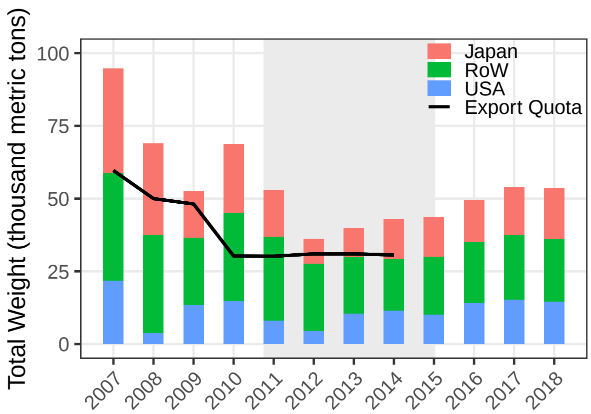
	Panel A. Dep. Var.: Outcomes over 2007–2012						
	Employment	Revenue	Exports	Product Variety	Total Assets	Material Costs	Production Workers
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated$_f$	-0.081	-0.106	-0.159	-0.151	-0.178	-0.113	-0.087
	(0.054)	(0.083)	(0.127)	(0.052)	(0.072)	(0.104)	(0.061)
Num. Obs.	550	550	350	550	550	550	550

	Panel B. Dep. Var.: Outcomes over 2007–2017						
	Employment	Revenue	Exports	Product Variety	Total Assets	Material Costs	Production Workers
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated$_f$	-0.161	-0.214	0.048	-0.157	-0.201	-0.179	-0.110
	(0.092)	(0.114)	(0.181)	(0.072)	(0.103)	(0.139)	(0.098)
Num. Obs.	450	450	300	450	450	450	450

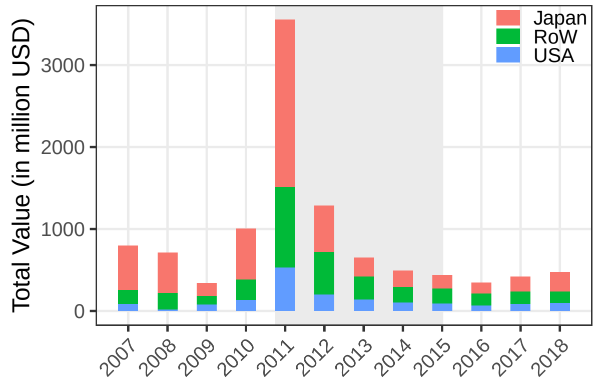
Notes. Standard errors clustered at the firm level are reported in parentheses. This table reports estimates of β from equation (3.3), omitting the NAICS 2-digit fixed effects δ_j. The specification is otherwise identical to Table 2. The dependent variable is the change in the log of the indicated outcome between 2007 and 2012 in Panel A and between 2007 and 2017 in Panel B. Material costs are the cost of materials and parts. The sample consists of manufacturing firms in the CMF. The sample size drops for export outcomes because of zeros and the log transformation, and missing information. Observation counts are rounded in accordance with Census disclosure requirements.

B.2 Additional Figures

Figure B.1: China's 2010 Rare Earth Export Restriction: Imported Quantities and Values from Comtrade



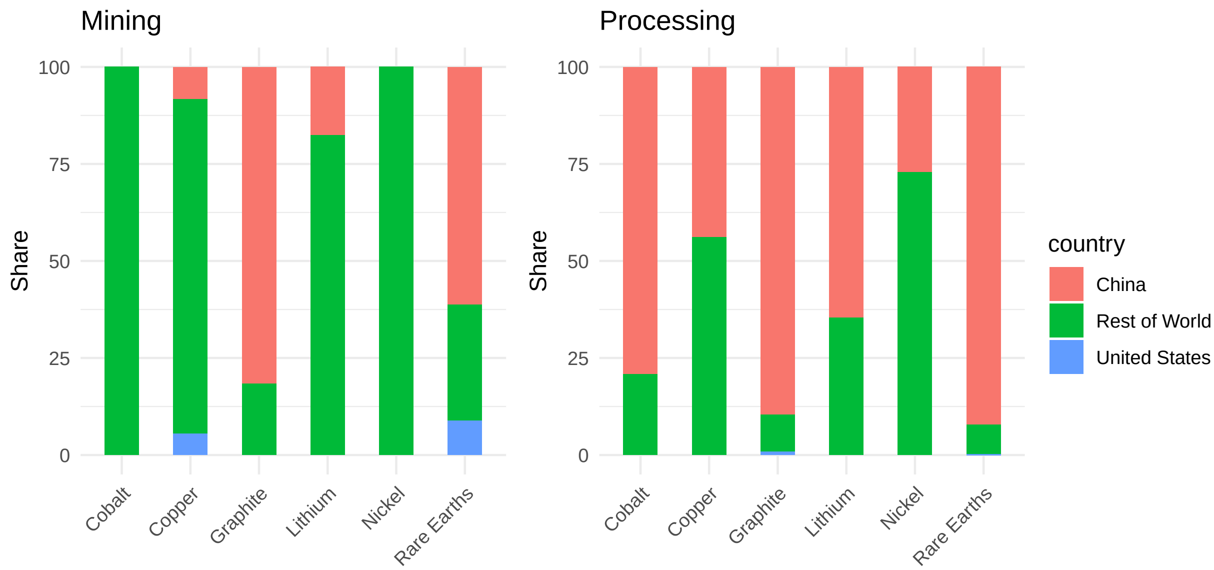
A. Imported Quantities by Destination



B. Imported Values by Destination

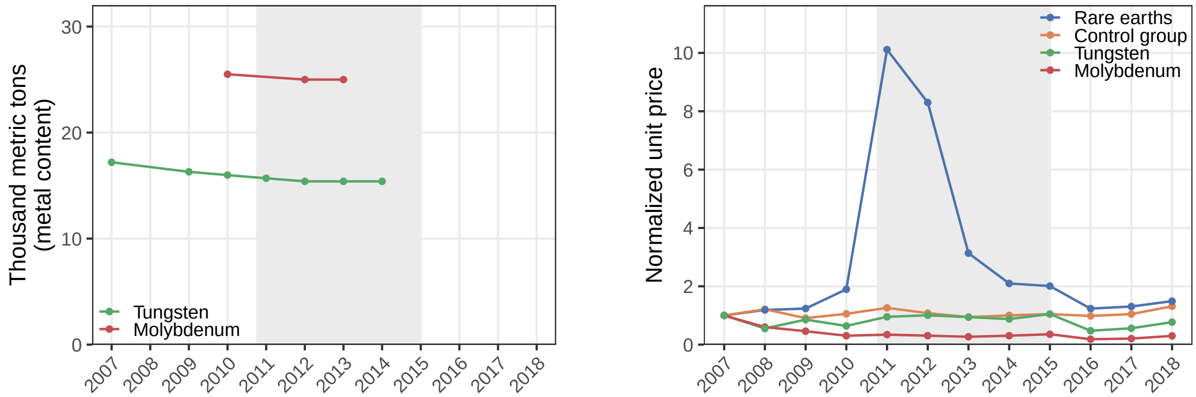
Notes. Panel A plots China's export quota and total rare earth quantities imported from China by the US, Japan, and the rest of the world. Panel B plots the corresponding imported values. Imported quantities and values are sourced from Comtrade based on the 6-digit HS codes reported in Table B.2; the export quota is the same as in Panel A of Figure 1. In both panels, the shaded region denotes the restriction period, from October 2010 to January 2015.

Figure B.2: China's Dominance in Mining and Refining Capacity of Selected Critical Minerals in 2023



Notes. This figure reports global market concentration by country for mining and refining industries of selected critical minerals in 2023. The information is obtained from International Energy Agency (2024). The IEA data do not cover tungsten and molybdenum.

Figure B.3: Tungsten and Molybdenum: China's Export Quotas and US Import Prices



A. China's Export Quotas for Tungsten and Molybdenum

B. US Average Import Prices of Rare Earths, Control Group Minerals, Tungsten, and Molybdenum

Notes. Panel A plots China's annual export quotas for tungsten and molybdenum in metric tons of metal content. The quotas are obtained from the tungsten chapters of the USGS Minerals Yearbook (U.S. Geological Survey, 2010–2013b, 2008–2019), the WTO panel report (World Trade Organization, 2014), and the USTR oral statement (Office of the United States Trade Representative, 2013). Panel B plots the average US import prices of rare earths, control group critical minerals, tungsten, and molybdenum, computed as unit values from Comtrade. The 2007 level is normalized to one. In both panels, the shaded region denotes the rare earth restriction period, from October 2010 to January 2015.

C. Simple Model

In this section, we develop a simple partial equilibrium model that rationalizes our main empirical findings. There is an entrepreneur who owns a firm and earns income from the firm's profits. It takes wages w, rare earth import cost m, and demand as given. We normalize the domestic price level to one, so profits are in real terms.

Preferences. The entrepreneur is risk-averse with constant absolute risk aversion:

Assumption 1. *$U(\pi) = -\exp(-\kappa\pi)$, where $\kappa > 0$ is the coefficient of absolute risk aversion.*

Using a second-order approximation, the certainty equivalent of the entrepreneur is given as[16]:

$$\mathbb{E}[\pi] - \frac{\kappa}{2}\mathrm{Var}[\pi], \tag{C.1}$$

where π is total profit and $\mathrm{Var}[\pi]$ is the variance of profits.

Core product. Each firm produces its core product, which is its most profitable product, and can also produce non-core products. We assume that the core product can be produced without fixed costs in both domestic and foreign markets (or it can be considered as if the firm already paid for them), and its production requires labor and rare earths imported from China. Profits of the core product are given as

$$\pi^c = \frac{1}{\eta}\Big(\frac{\mu w^\alpha m^{1-\alpha}}{a_c}\Big)^{1-\eta}(D_d + D_x), \tag{C.2}$$

where the superscript c denotes the core product, $\eta > 1$ is the elasticity of substitution, and $\mu \equiv \eta/(\eta-1)$ is the constant markup. Firms produce the core product using labor and rare earths from China with the Cobb–Douglas labor share α, where we normalize the Cobb–Douglas constant so that the unit cost of the input bundle is $w^\alpha m^{1-\alpha}$. m is the import cost of rare earths, and a_c is core-product productivity. D_d and D_x are domestic and foreign demand shifters.

[16]The second-order Taylor approximation of the utility function around $\mathbb{E}[\pi]$ gives $\mathbb{E}[U(\pi)] \approx U(\mathbb{E}[\pi]) + \frac{1}{2}U''(\mathbb{E}[\pi])\mathrm{Var}[\pi]$. The risk premium r is defined by $\mathbb{E}[U(\pi)] = U(\mathbb{E}[\pi] - r)$, and a first-order approximation gives $U(\mathbb{E}[\pi] - r) \approx U(\mathbb{E}[\pi]) - r\,U'(\mathbb{E}[\pi])$. Combining the two equations gives $r = -\frac{1}{2}\frac{U''}{U'}\mathrm{Var}[\pi] = \frac{\kappa}{2}\mathrm{Var}[\pi]$.

π^c is stochastic because rare earth import costs m is stochastic. We denote its distribution by h, with mean $\mathbb{E}_h[\pi^c]$ and variance $\mathrm{Var}_h[\pi^c]$.

Entrepreneurial Capability. The entrepreneur is endowed with a limited unit mass of capability (e.g., managerial time), which can be used either to reduce geopolitical risks associated with the core product (e.g., by finding alternative suppliers, signing long-term contracts, or holding inventories) or to improve the quality of non-core products.

If the entrepreneur invests $e \in [0, 1]$ of capability in reducing risks, the distribution of core profits changes from h to

$$h_e(\pi) = \big(1 - \rho(e)\big)h(\pi) + \rho(e)\,\delta\big(\pi - \mathbb{E}_h[\pi]\big), \tag{C.3}$$

where $\delta(\cdot)$ is the Dirac delta function, which puts mass one at $\mathbb{E}_h[\pi]$, and $\rho(\cdot)$ is continuously differentiable with $\rho(0) = 0$, $\rho(1) = 1$, and $\rho' > 0$. It is straightforward to check that h_e preserves the mean of h and scales the variance by $1 - \rho(e)$:

$$\mathbb{E}_{h_e}[\pi^c] = \mathbb{E}_h[\pi^c], \qquad \mathrm{Var}_{h_e}[\pi^c] = \big(1 - \rho(e)\big)\,\mathrm{Var}_h[\pi^c]. \tag{C.4}$$

Therefore, investing more in risk reduction lowers the variance of core profits without changing their expected value.

Non-Core Products. The firm can also produce a measure one of potential non-core products. Following Bernard et al. (2011), each non-core product has a quality draw λ from the continuous cumulative distribution G, whose support is $[0, \infty)$. The quality of a non-core product is λq, where $q = q(1 - e)$ and $q(\cdot)$ is continuously differentiable with $q' > 0$ and $q(0) > 0$. That is, capability devoted to non-core products improves the quality of all non-core products. We assume that non-core products are produced only with labor, so they are not directly exposed to risks associated with rare earth import costs. Non-core products can be sold in market $k \in \{d, x\}$ after incurring a market-specific fixed cost of f_k units of labor. Profits of non-core product λ in market k are given as

$$\pi_k^n(\lambda; e) = \frac{1}{\eta}\left(\frac{\mu w}{a_n \lambda q}\right)^{1-\eta} D_k - w f_k, \tag{C.5}$$

where a_n is the productivity of non-core products. Due to fixed costs, the firm sells non-core product λ in market k only when $\lambda \geq \lambda_k^*(e)$, where the cutoff is given as

$$\lambda_k^*(e) = \frac{\mu w}{a_n q(1-e)} \left(\frac{\eta w f_k}{D_k}\right)^{\frac{1}{\eta-1}}. \tag{C.6}$$

Using the cutoff, profits can be rewritten as $\pi_k^n(\lambda; e) = w f_k \left[(\lambda/\lambda_k^*(e))^{\eta-1} - 1\right]$, and total profits from non-core products are

$$\pi^n(e) = \sum_{k\in\{d,x\}} \int_{\lambda_k^*(e)}^{\infty} \left[\left(\frac{\lambda}{\lambda_k^*(e)}\right)^{\eta-1} - 1\right] w f_k \, dG(\lambda). \tag{C.7}$$

Note that both cutoffs are proportional to $1/q(1-e)$. If the entrepreneur invests more in risk reduction, the quality of non-core products falls, and both cutoffs increase.

We make the following assumption:

Assumption 2. *(i) Exporting non-core products is harder than selling them domestically, $f_x/D_x > f_d/D_d$, so that $\lambda_x^*(e) > \lambda_d^*(e)$; and (ii) core-product productivity a_c is sufficiently high so that its profit is always higher than the total profits from non-core products for any level of e (i.e., $\pi^c > \pi^n(e)$, $\forall e \in [0,1]$).*

Assumption (i) implies that only a subset of non-core products is exported. Assumption (ii) implies that total profits from the core product are larger than those from non-core products.[17]

The Entrepreneur's Problem. The entrepreneur's trade-off is that it has to use limited capability either to reduce the risks of the core product or to improve the quality of non-core products. The maximization problem of the entrepreneur is given as follows:

$$\max_{e\in[0,1]} \left\{\mathbb{E}_h[\pi^c] - \frac{\kappa}{2}\big(1-\rho(e)\big)\,\mathrm{Var}_h[\pi^c] + \pi^n(e)\right\}. \tag{C.8}$$

Because profits from non-core products are deterministic, the variance of total profits equals the variance of core profits.

[17] Because quality draws have support $[0,\infty)$, some non-core products earn more per unit than the core product. However, each non-core product has measure zero, whereas the core product has measure one.

The optimal e is determined by the following first-order condition:

$$\frac{\kappa}{2}\,\rho'(e)\,\mathrm{Var}_h[\pi^c] = -\frac{d\pi^n(e)}{de}. \tag{C.9}$$

The left-hand side is the marginal benefit of reducing risks, and the right-hand side is its marginal cost, the forgone profits from non-core products. For simplicity, we assume that an interior solution exists whenever $\mathrm{Var}_h[\pi^c] > 0$, and e^* then denotes such a solution.

Geopolitical risk. We model an increase in geopolitical risk as a mean-preserving spread of h, which increases $\mathrm{Var}_h[\pi^c]$ without changing $\mathbb{E}_h[\pi^c]$. We consider a spread of π^c rather than of m, because a mean-preserving spread of m would also change $\mathbb{E}_h[\pi^c]$ by equation (C.2). In our context, the 2010 export restriction increased the perceived risk of future disruptions, while rare earth imports returned to their pre-shock levels after 2012 and China abolished its export quota in January 2015. We therefore compare two steady states that differ only in perceived risk.

Proposition 1. *If h_1 is a mean-preserving spread of h_0, the capability invested in risk reduction increases, $e_1^* > e_0^*$.*

Proof. See Appendix C.1 for the proof. □

Proposition 2. *Suppose that h_1 is a mean-preserving spread of h_0. Then:*

(i) The firm drops its marginal non-core products, and the numbers of non-core products sold domestically and exported decrease. In each market k, the non-core products that exit market k are those with $\lambda \in \left[\lambda_k^*(e_0^*), \lambda_k^*(e_1^*)\right)$, the lowest-quality products that the firm was selling.

(ii) Expected domestic revenues, exports, and employment decrease, as all surviving non-core products sell less because their quality falls (intensive margin), and the number of non-core products produced decreases (extensive margin). However, expected revenue, exports, wage bill, and rare earth import expenditure of the core product do not change.

Proof. See Appendix C.1 for the proof. □

Proposition 3. *Suppose that h_1 is a mean-preserving spread of h_0, and suppose instead that G is Pareto with the lower bound 1 and the shape parameter $\theta > \eta - 1$, where $\lambda_d^*(0) \geq 1$. Then,*

(i) the number of exported products decreases;

(ii) expected total exports decrease proportionally less than expected domestic revenues, and expected exports per product increase if expected exports of the core product exceed average exports of an exported non-core product.

Proof. See Appendix C.1 for the proof. □

These propositions imply that with higher geopolitical risks, the share of the core product in the firm's revenues increases, as the firm focuses on its core competence by dropping its marginal products.

After the 2010 export restriction, suppose perceived geopolitical risk increased as a mean-preserving spread of h, so that e^* increases. Propositions 1–3 provide predictions consistent with our empirical findings of persistent declines in revenues and employment, drops in product variety produced, and relatively stable exports, with exports per product increasing.

C.1 Proofs

Proof of Proposition 1.

Proof. Let V denotes for $\mathrm{Var}_h[\pi^c]$, on which the objective in equation (C.8) depends together with $\mathbb{E}_h[\pi^c]$ and nothing else about h, and let V_0 and V_1 denote the variances of core profits under h_0 and h_1. A mean-preserving spread leaves $\mathbb{E}_h[\pi^c]$ unchanged and raises the variance, so $V_1 > V_0 \geq 0$, and it shifts the objective by $-\frac{\kappa}{2}\big(1-\rho(e)\big)(V_1 - V_0)$, which is strictly increasing in e because $\rho' > 0$ and $V_1 > V_0$. The objective therefore has strictly increasing differences in (e, V): the marginal benefit of reducing risks rises with the level of risks. Every maximizer e_1^* under h_1 consequently weakly exceeds every maximizer e_0^* under h_0 (Milgrom and Shannon, 1994). □

Proof of Proposition 2.

Proof. By Proposition 1, $e_1^* > e_0^*$ for any optimal e_0^* under h_0 and any optimal e_1^* under h_1. Both cutoffs are proportional to $1/q(1-e)$ by equation (C.6), so with $q' > 0$ both rise by the common factor $q(1-e_0^*)/q(1-e_1^*) > 1$. A non-core product sells in market k precisely when $\lambda \geq \lambda_k^*(e)$, so the products that leave market k are those with $\lambda \in \big[\lambda_k^*(e_0^*), \lambda_k^*(e_1^*)\big)$, the lowest-quality of those the firm had been selling there. The number it still sells in market k, $1 - G(\lambda_k^*(e))$, strictly falls as e rises, because G is strictly increasing on its support $[0, \infty)$. Since

$\lambda^*_x(e) > \lambda^*_d(e)$ under Assumption 2(i), products below $\lambda^*_d(e)$ reach neither market, so the firm abandons those with $\lambda \in \left[\lambda^*_d(e^*_0), \lambda^*_d(e^*_1)\right)$ altogether.

For each λ and each market k, the revenue and the employment of a non-core product both fall as $\lambda^*_k(e)$ rises, so every product still sold in k sells less there. All values of the core product are proportional to π^c, so its expected revenue, exports, wage bill, employment, and rare earth import expenditure are the same multiples of $\mathbb{E}_h[\pi^c]$ whatever e the entrepreneur chooses, and a mean-preserving spread does not change $\mathbb{E}_h[\pi^c]$, so the move from e^*_0 to e^*_1 leaves all of them unchanged. With the values of non-core products deterministic, expected domestic revenues, exports, and employment of the firm all decline, while those core magnitudes hold steady. □

Proof of Proposition 3.

Proof. Let $G(\lambda) = 1 - \lambda^{-\theta}$ for $\lambda \geq 1$. Cutoffs rise in e and $\lambda^*_x(e) > \lambda^*_d(e)$ under Assumption 2(i), so $\lambda^*_k(e) \geq \lambda^*_d(0) \geq 1$ for all $e \in [0, 1]$ and $k \in \{d, x\}$. The proofs of Propositions 1 and 2 apply to this G.

Let λ^*_k denotes for $\lambda^*_k(e)$, the measure of non-core products sold in market k is $N_k = 1 - G(\lambda^*_k) = (\lambda^*_k)^{-\theta}$, while their average sales $s_k = \eta w f_k \theta/(\theta - \eta + 1)$ do not depend on the cutoff, so total non-core revenue there is $R_k = s_k N_k$. By Proposition 1 and the proof of Proposition 2, both cutoffs rise by the same factor $\psi \equiv q(1 - e^*_0)/q(1 - e^*_1) > 1$, which scales N_d, N_x, R_d, and R_x down alike by $\psi^{-\theta} < 1$. The core product bears no fixed cost and is always exported, so the count of exported products, $1 + N_x$, falls.

Expected sales of the core product in market k, denoted as C_k, do not move, by Proposition 2(ii). Revenues of non-core products being deterministic, the firm's expected sales in market k, which are domestic revenues when $k = d$ and exports when $k = x$, change proportionally by

$$-\left(1 - \psi^{-\theta}\right)\frac{R_k/C_k}{1 + R_k/C_k},$$

with R_k evaluated at e^*_0, so the decline is larger the larger is R_k/C_k. Substituting equation (C.6) at $e = e^*_0$ leaves k entering R_k/C_k only through $(f_k/D_k)^{1-\theta/(\eta-1)}$, an exponent that is negative because $\theta > \eta - 1$, so R_k/C_k decreases in f_k/D_k; since $f_x/D_x > f_d/D_d$ under Assumption 2(i), $R_x/C_x < R_d/C_d$, and expected total exports fall proportionally less than expected domestic revenues. Expected exports per exported product, $(C_x + s_x N_x)/(1 + N_x)$, have derivative $(s_x - C_x)/(1 + N_x)^2$ with respect to N_x; neither C_x nor s_x moves and N_x falls, so they rise whenever $C_x > s_x$, that is, whenever expected exports of the core product exceed average exports of an exported non-core product. □

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