Rare Earth Supply Chains: Predatory Pricing for Strategic Dominance*

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Abstract

Rare earth elements are critical inputs for high-technology industries, yet their global supply chain, particularly in the processing stage, is dominated by China. We develop a quantifiable multi-country general equilibrium model with three vertically linked sectors: mining, refining, and advanced manufacturing. In this model, a vertically integrated incumbent refining firm deters entry through strategic overproduction, endogenously determining market structure in the refining sector. Calibrating the model to match key moments in global rare earth trade and using novel rare earth pricing data, we show that low input substitutability gives China strategic power. Counterfactual analysis evaluates the welfare effects of Western entry subsidies, the 2011 Chinese export restrictions, and supply chain diversification policies.

Keywords: Critical minerals, global supply chains, market structure, predatory pricing, trade policy, geoeconomics
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1. Introduction

Rare earth elements have become increasingly critical inputs for high-technology and green energy industries, including electric vehicles, wind turbines, and defense systems. Yet the global rare earth supply chain is highly concentrated, particularly in the refining and processing stage. Although mining activities are geographically dispersed across countries, China dominates the midstream refining market through a vertically integrated supply chain that extends from upstream extraction to downstream processing. This concentration has become an important issue in the broader US–China geopolitical rivalry. Western policymakers have expressed concern that China is strategically overproducing refined rare earths to deter the entry of Western firms into the industry.[1]

The 2010–2011 Senkaku Islands episode offered a stark demonstration of this leverage. Following a diplomatic dispute between China and Japan, China imposed export restrictions on rare earths that triggered immediate supply shortages and sharp price spikes. The downstream consequences were severe: Japan's high-technology industries, heavily dependent on Chinese rare earth inputs, faced acute disruption. A joint WTO complaint filed by the United States, European Union, and Japan ultimately succeeded, with the WTO ruling against China in 2014. However, the episode left an enduring lesson about the risks of single-supplier dependence in critical mineral supply chains.

This paper asks: what are the implications of predatory pricing for global rare earth supply chains, and what policies can effectively counteract them? We develop a quantifiable general equilibrium model of the global rare earth supply chain with three vertically linked sectors (mining, refining, and advanced manufacturing) and N countries. The refining sector is the crux of the analysis. It features at most two large firms competing in a Stackelberg duopoly: a Chinese incumbent with a first-mover advantage and a potential Western entrant who must incur a fixed cost to enter. The incumbent can deter entry by committing to sufficiently high output quantities, reducing the entrant's prospective profits below the entry threshold. Market structure in the refining sector, be it monopoly or duopoly, arises endogenously from the interaction among the incumbent's pricing strategy, the entrant's fixed costs, and trade frictions across the supply chain.

The model features several key mechanisms. First, the incumbent's Stackelberg leadership

[1] See the White House Office of Trade and Manufacturing Policy (p. 12 OTMP, 2018), the testimony of Nikakhtar (pp. 10, 34 2022), and the US House Select Committee on the Strategic Competition with the Chinese Communist Party (pp. 3–4, 19 US House, 2025). In the media, The Wall Street Journal (2024) reports that *"overproduction keeps rare earth prices low, challenging Western efforts to reduce their reliance on Chinese supplies,"* and The Economist (2026) notes that *"China long used predatory pricing to deter competition, recouping losses through magnet and electric-vehicle sales."*

is grounded in credible commitment: the rare earth refining industry requires substantial upfront investment in specialized equipment, environmental compliance, and technical expertise, making capacity decisions difficult to reverse. Second, low substitutability between rare earth inputs and other factors in downstream manufacturing is central to China's strategic power: it is precisely because downstream firms cannot easily substitute away from rare earths that the incumbent can extract rents and deter rivals. Third, the vertical structure of the supply chain matters: entry deterrence in refining has consequences not only for refining markets but for upstream mining and downstream manufacturing as well.

We take the model to the data using a combination of global bilateral trade flows, confidential US firm-level microdata, and novel Chinese price data on domestic and export prices for key rare earth outputs including Neodymium and Dysprosium. With the calibrated model in hand, we evaluate three counterfactuals. First, we assess the welfare consequences of the 2011 export restriction, decomposing effects across the upstream, midstream, and downstream stages of the supply chain. Second, we examine a US entry subsidy policy, exploiting a natural anchor from the US Department of Defense's Price Protection Agreement to purchase refined rare earths at \$110 per kilogram. Third, we consider the implications of expanding Western mining capacity as a supply diversification strategy.

Several results emerge from the counterfactuals. First, the 2011 restriction lowered welfare everywhere, and the presence of a Western refiner sharply changes its incidence. Absent US entry, the restriction reduces welfare by 2.03% of downstream revenue in China, 0.20% in the US, and 0.33% in the rest of the world. Losses outside China operate almost entirely through consumer surplus, while China's own loss is driven by the domestic production quota it implemented along with the export restrictions, rather than the export quota alone. China's loss is only partly offset by higher fiscal revenue and by downstream profits shifting toward China. When the US entrant is active, US losses fall by 94.3%, while losses in the rest of the world grow by 22.3% and China's loss is essentially unchanged. The additional refined supply insulates US downstream users, but it also competes away the refining profits that fringe producers elsewhere earn from the restriction.

Second, we evaluate the Department of Defense price floor, which our calibration maps into an production subsidy of 25%. The subsidy raises welfare in every region, by 0.04% of downstream revenue in the US, 0.10% in China, and 0.11% in the rest of the world, because entry lowers refined prices and the resulting consumer surplus gains exceed the loss in refining profits. Interestingly, China gains the most from the US subsidy policy, since its downstream sector is the most intermediate-input intensive and therefore benefits most from cheaper refined output. This is an unintended consequence of a US policy designed to reduce dependence on China. Strikingly, US welfare is maximized at a subsidy rate just *below* the entry threshold: at that rate the incumbent limit-prices to keep the entrant out, so the US captures low prices without anyone paying the subsidy or the fixed entry cost. Once entry occurs, the incumbent's markup jumps up in the US and other countries, while it decreases in China. The increase is largest in the US, precisely where it had been compressing its markup hardest to deter the rival. In China, by contrast, the incumbent had not been limit-pricing aggressively, so actual entry brings competitive pressure that lowers its home markup, leading to differential responses of the incumbent's markups to actual entry across markets.

Third, we evaluate supply diversification strategies through mining versus refining. Mining diversification is modeled as an exogenous change in mining productivity that rationalizes the observed change in mining production shares from 2010 to 2020, and refinery diversification as US entry into refining. Calibrating the 2011 restriction to the 2010 mining production patterns, US welfare falls by 0.27%. The diversification in mining production that actually occurred over the subsequent decade absorbs roughly a quarter of that loss, reducing it to 0.20%, whereas a domestic refinery absorbs two thirds of it, reducing it to 0.09%. With diversification in mining and refining, the loss falls to 0.01%, suggesting that the two strategies complement one another. In normal times without any Chinese export restriction, mining diversification and refinery entry raise US welfare by 0.04% and 0.07% on their own and by 0.13% together. These exercises suggest that the supply chain bottleneck lies in refining rather than mining and both diversification strategies complement each other in the vertical supply chain.

Finally, we characterize China's optimal export tax and find that it is disciplined by the entry threshold rather than by the usual terms-of-trade tradeoff. A uniform export tax against the world is optimal at 53%, an epsilon below the rate at which US entry becomes profitable, and yields a welfare gain of 0.10% of Chinese downstream revenue; beyond that point entry erodes the tax base and the gain shrinks and then turns negative. The logic resembles a Laffer curve, but here the elasticity of the tax base moves endogenously with market structure and firm markups. China's optimal bilateral tax of 35% delivers a gain of 0.002% of its own downstream revenue while imposing a US loss of 0.018%, so the instrument is about eight times more effective as a weapon than as a source of gains. Entry deterrence is essential to all of the magnitudes in the counterfactuals. In versions of the model with constant markups, or with oligopolistic pricing but no Stackelberg deterrence, the US gain from its own subsidy falls from 0.0864% to −0.0015%–0.0042%.

Related Literature. Strategic trade policy has been a central topic in international economics (Dixit, 1980, 1984; Spencer and Brander, 1983; Brander and Spencer, 1985; Eaton and

Grossman, 1986; Bagwell and Staiger, 1994; Maggi, 1996; Atkin et al., 2024); see Helpman and Krugman (1989), Brander (1995), and Head and Spencer (2017) for comprehensive reviews. Most of the prior literature has been theoretical in nature. Our model builds on the pioneering work of Brander and Spencer (1981), who study profit-shifting motives for tariffs under foreign firms' Stackelberg entry deterrence, extending the framework developed by Dixit (1979). Horstmann and Markusen (1992) present a model in which monopoly or duopoly arises depending on location decisions by multinational firms, based on on firm- or plant-specific fixed costs. Our main contribution to this literature is developing a quantifiable model in which market structure arises endogenously from strategic interaction between oligopolistic firms and trade policies, and using this model to study the supply chain consequences of such strategic interaction, which has been largely absent from theoretical work on strategic trade policy. While recent trade papers have studied firm's market power in pricing and pass-through (e.g. Atkeson and Burstein, 2008; Edmond et al., 2015; Alviarez et al., 2023), this paper studies entry deterrence and its consequences for the global supply chain of critical minerals.

This paper is also related to the international trade literature on the transmission of shocks, risk and resilience in global supply chains (Boehm et al., 2019; Bonadio et al., 2021; Carvalho et al., 2021; Dhyne et al., 2021; Khanna et al., 2022; Dhyne et al., 2022; Grossman et al., 2023, 2024; Castro-Vincenzi et al., 2024). The most closely related paper is Alfaro et al. (2025), who study directed technological change following China's 2010 export restrictions and find that industries most dependent on rare earths generated significantly more patents directed at substituting away from rare earth usage after the restrictions were imposed. Domínguez-Iino et al. (2026) study market power and interdependence among critical mineral markets, which arise because advanced batteries require multiple minerals as inputs, and their geopolitical consequences for the green technology transition. Our main contribution to this literature is to introduce a refinery sector in a vertically intergrated rare earths supply chain, and to study the implications of deterred entry on upstream and downstream sectors.

Our paper is also related to the literature on commodity trade (e.g. Fally and Sayre, 2018; Farrokhi, 2020; Farrokhi and Pellegrina, 2023; Farrokhi et al., 2025; Pellegrina and Sotelo, 2025; Dominguez-Iino, 2026; Hsiao, 2026; Toma et al., 2026). Rare earths are of particular interest because they are heavily dominated by China, and they are critical inputs to many high-tech and defense sectors, contributing to geopolitical tension between the US and China. Previous studies have documented that although commodities represent a small share of total trade values, their low substitutability implies large welfare effects from commodity trade flows. We further quantitatively show that this low substitutability is precisely what confers China strategic power over its trading partners.

Finally, our paper contributes to a fast-growing literature on geoeconomics, which studies how states deploy economic instruments—tariffs, sanctions, export controls, investment screening—to advance strategic objectives (Kleinman et al., 2024; Becko and O'Connor, 2024; Thoenig, 2024; Clayton et al., 2026; Martin et al., 2008; Flynn et al., 2025; Levchenko et al., 2026); see Mohr and Trebesch (2025) for a review. Clayton et al. (2026) develop a general framework in which a hegemon exercises power over a rival along economic linkages and characterize the optimal use of such instruments, while Becko and O'Connor (2024) study how the anticipation of conflict shapes countries' incentives to integrate with, or disengage from, adversaries. Closest to our setting substantively, Flynn et al. (2025) show that exposure to foreign political risk directs innovation toward reducing reliance on risky suppliers, including in critical minerals, and Martin et al. (2008) find that de-risking can be self-undermining, since lower trade dependence also weakens the incentives for restraint that dependence creates. This literature typically takes the set of producers and the structure of the relevant market as given, so that a country's leverage is a function of existing trade linkages. Our contribution is to make the existence of an alternative supplier itself an object of strategic choice, and to show that this changes the impact of the instrument. In our model the source of leverage is not a tax or a sanction but a quantity commitment, which is unobserved in trade data yet shapes the market structure that determines every country's exposure; and the exercise of leverage is self-limiting, since a sufficiently aggressive export tax destroys the very dominance that made it valuable by making Western entry profitable. Our framework also quantifies the notion of a supply-chain "chokepoint" that recurs in policy discussion: the incumbent's power is measured by the substitutability of refined inputs downstream and by the entrant's fixed cost, and our counterfactuals trace how changes in policy in both dimensions moves the resulting entry threshold.

2. Data and Background

2.1 Data

We obtain rare earth price data from Asian Metal, a data company that collects mineral price quotes directly from producers and traders in China. The price series cover the key rare earth refinery products, including neodymium-praseodymium (NdPr) oxide and dysprosium oxide. For these products, the data report the ex-works (EXW) China prices of rare earth mining and refining output, inclusive of Chinese value-added tax.[2] The data also report the free-on-board (FOB) China price of refinery output exported to the US. The difference between the EXW and FOB price series allows us to identify price increases driven by export-specific taxes or quotas separately from those affecting all Chinese domestic buyers.

US rare earth import quantities and values, world mine production by country, and US production come from the Mineral Commodity Summaries of the United States Geological Survey (USGS). All quantities are expressed in rare earth-oxide (REO) equivalent weight. We supplement this with the SEC filings of MP Materials, which is the only US rare earth processing company. The filings report the firm's production, sales, and the revenue received under the Department of Defense price-floor program.

Our input-output tables come from OECD Inter-Country Input-Output tables and bilateral trade data at the 6-digit HS code level from BACI.

2.2 Background

China's Dominance in Rare Earth Supply Chain. Rare earths are a group of 17 metallic elements that have become critical inputs to modern high-tech and defense industries. They are essential to the permanent magnets used in electric vehicles and wind turbines, as well as to missile guidance systems, jet engines, and satellite communication systems (USGS, 2024).

China has dominated the global rare earth supply chain since the 1990s. The Chinese government began investing in rare earth research and production in the 1970s, and by the 1990s Chinese producers were exporting at prices low enough to drive competitors from other countries, including in the US, out of the market. Cheap capital, low labor costs, and lax environmental regulation kept Chinese production costs down, building a supply chain that spans mining, refining, and magnet manufacturing (Andrews-Speed and Hove, 2023). At the same time, stricter environmental regulation raised the cost of rare earth production in advanced economies. For instance, at Mountain Pass, then the largest US producer, repeated releases of radioactive materials into the surrounding desert led to regulatory penalties and the suspension of refining operations in 1998, and the mine ceased production altogether in 2002 as it could no longer compete with low priced Chinese supply.

The rare earth supply chain is vertically structured. Ore extracted at the mining stage must be refined into usable intermediate products. The ore is first separated into rare earth oxides such as neodymium-praseodymium (NdPr) oxide and dysprosium oxide, then reduced to rare earth metals and cast into alloys. We refer to these stages collectively as refining. The refined outputs are the essential inputs for permanent magnets, the critical components of

[2] Prices are quoted in RMB per metric ton for material of at least 99.5 percent purity.

high-tech products. At its peak around 2010, China accounted for roughly 95% of global rare earth mining, and it still retains about 90% of the world's refining capacity today (Figure 2).

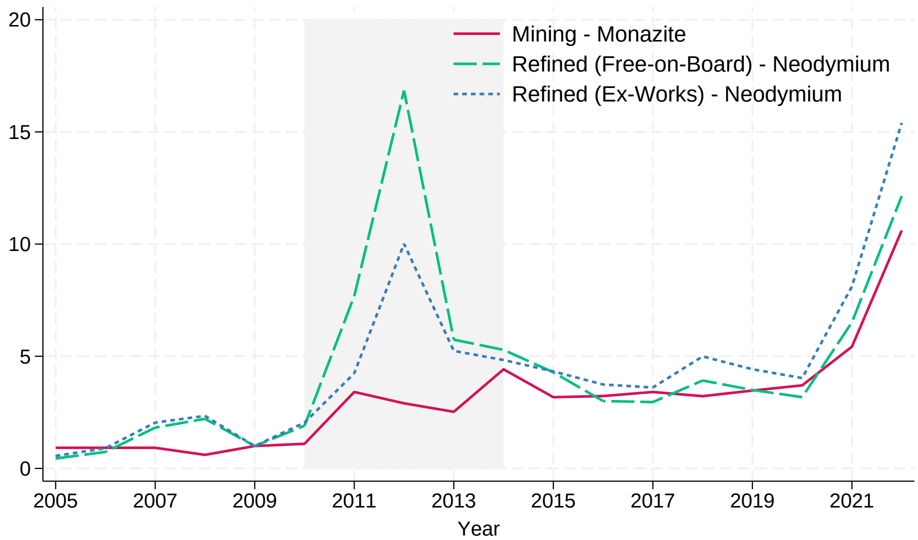
2011 Export Restriction. China's 2011 rare earth export restriction demonstrated that dominance of a critical input could be used as a geopolitical instrument. The episode raised serious concerns among Western policymakers about the risks of supply chain concentration and about China's willingness to leverage its dominant market position for strategic ends.

The geopolitical dimension of the restriction became evident during the 2010 Senkaku Islands dispute between China and Japan. After the Japanese Coast Guard arrested the captain of a Chinese fishing trawler near the contested islands, China imposed export quotas that effectively cut off rare earth supplies to Japan, whose high-tech industries were heavily dependent on Chinese refined rare earth products. The quotas were not targeted at Japan alone but applied to all export destinations, as WTO rules prohibit discrimination among trading partners. China simultaneously imposed quotas on domestic production, which reduced overall supply. The Chinese government justified these quotas as environmental policy (which is technically consistent with WTO rules) intended to limit the damage caused by rare earth mining and refining, and it denied any direct link between the export restrictions and the territorial dispute. The episode triggered immediate supply shortages and sharp price spikes in global rare earth markets.

In response to this restriction, the US, European Union (EU), and Japan jointly filed a WTO complaint in 2012 arguing that China's export restriction was illegal. The WTO ruled against China in 2014, finding that the restrictions violated international trade rules by favoring domestic firms over foreign competitors and were not genuinely justified by China's environmental defense under GATT Article XX. China subsequently lifted all rare earth export quotas by January 2015.

Figure 1 plots price spikes around the export restriction. There are two key patterns. First, the price of the raw ore, monazite, responded less than that of refined output, neodymium oxide. This suggests that the restriction on refined output was more binding than that on mined ore, and that refining was the real bottleneck in the supply chain. Second, the spike in China's domestic transaction price was smaller than the spike in export prices measured free on board at Chinese ports. We measure China's domestic prices using ex-works prices, which include value-added taxes and licensing fees, while free-on-board prices additionally reflect the fees that apply to the export market. The difference between the two therefore reflects the different magnitudes of the restrictions imposed on domestic and on foreign sales. We observe a similar wedge between ex-works and free-on-board prices for dysprosium, a heavy rare earth produced almost exclusively in China (Figure A.2).

Figure 1: China's 2011 Rare Earth Export Restriction and Prices



Notes. This figure plots three prices of rare earth output, raw mining ore (Monazite), free-on-board prices at Chinese ports and Chinese domestic transaction prices, measured as ex-works prices, of refined rare earth output (Neodymium Oxide).

Figure 2: China's Dominance in Rare Earth Mining and Refining

A. China's Share in Global Mining Production B. US Import Shares from China in Refined Rare Earth

Notes. This figure illustrates China's dominance in rare earth mining and refining over time. Panel A plots China's global mining production share. Panel B plots US import shares of refined rare earth from China (red solid line) and China's shares in global refinery production (blue dots). The gray shaded area represents 2011–2015, during which the 2011 restriction was in place. The dashed lines represent averages over periods.

Mining vs. Refining. Figure 2 reports China's share of global rare earth mining and refining output around the 2011 restriction. Panel A shows China's share of mining output. Prior to the export restrictions, China accounted for approximately 95% of global mining output between 2005 and 2010. Its share fell during the restriction period of 2011–2015, as higher Chinese prices incentivized production elsewhere and it continued to fall thereafter as Western governments accelerated efforts to develop alternative supply chains due to the concern that such restrictions could be reimposed.

After 2015, mining became more diversified, driven by Western governments' efforts to reduce dependence on China. Mining at Mountain Pass in the US resumed in 2017 and Australia increased its mining production. Between 2015 and 2019, Australia accounted for 11% of global mining output and the US for 6% (Figure A.1). Moreover, the rapid expansion of global high-tech and green technologies raised demand for rare earth materials, which led other developing countries, such as Myanmar, to expand their mining operations.

Unlike mining, however, China's dominance of the refining stage has been little affected by the global reaction to the 2011-2015 event. In 2010, a year before the restriction was imposed, China's share in global production was 97% (GAO, 2010). Western producers have since established separation capacity outside China. MP Materials, a US firm, produced its first separated output at Mountain Pass in 2023, and Lynas, an Australian firm, has operated its plant in Malaysia since 2012. Their volumes nonetheless remain small relative to China's. The US still sources about 80% of its refined rare earth imports from China, and China accounts for roughly 90% of global refining output (IEA, 2024).[3]

Western policymakers and the media have also conjectured that China's strategic pricing, aimed at deterring Western firms' entry into the refining stage, is a barrier to diversification, alongside the radioactive waste that refining stages unavoidably generate and the large scale required for efficient production. Motivated by this concern, the US government decided to subsidize the US refining firm MP Materials. In July 2025 the US Department of Defense committed to a ten-year price floor of $110 per kilogram for MP Materials' refinery output, roughly double the prevailing market price at signing.

In the next section, we set up a model in which China's strategic pricing deters entry. Using this model, we quantitatively explore the welfare implications of such pricing, and conduct a counterfactual analysis of the implications of China's 2011 export restriction and the US subsidy program.

3. Model

3.1 Setup

The model is static. The world consists of N countries, indexed by $m, n \in \mathcal{N} = \{1, \ldots, N\}$, including the US and China. There are four sectors: (i) rare earth mining, (ii) rare earth refining, (iii) advanced manufacturing, and (iv) a homogeneous outside good sector. The

[3] China's US import shares were computed from USGS Mineral Commodities Surveys and China's global production shares come from International Energy Agency (IEA)'s annual reports. See Appendix A.1 for more details on data sources used for the figure.

first three sectors form a vertical supply chain: the mining sector is upstream of the refining sector, and the refining sector is upstream of the advanced manufacturing sector.

All three sectors are tradable, subject to iceberg trade costs $\tau^U_{nm}, \tau^R_{nm}, \tau^D_{nm} \geq 1$ and ad-valorem import tariffs $t^U_{nm}, t^R_{nm}, t^D_{nm} \geq 0$, respectively.

The mining and outside good sectors are perfectly competitive. The advanced manufacturing sector is monopolistically competitive, with a representative firm in each country.

The refining sector is the most interesting. In this sector, there are at most two large firms that compete à la Cournot, indexed by $f \in \{i, e\}$, and one fringe firm, indexed by $\tilde{f}$. The incumbent i is located in China, and a potential entrant e in the US may enter after incurring a fixed cost. The incumbent is a Stackelberg leader: it has a strategic advantage over the potential entrant in that it moves first, sets its quantity, and can credibly commit to it.[4] This first-mover advantage can deter rival entry and reduce the rival's profits even when entry occurs. The fringe firm always operates but does not engage in strategic interaction, charging a monopolistically competitive markup. Let $\mathcal{F}$ denote the set of operating firms. When both large firms operate, $\mathcal{F} = \{i, e, \tilde{f}\}$; otherwise, $\mathcal{F} = \{i, \tilde{f}\}$.

In each country, there is a representative household that supplies labor inelastically at wage W_n and owns the domestic firms.

3.2 Household

A representative household has quasi-linear preferences:

$$\begin{aligned} U_n &= C^0_n + R^D_n \ln C^D_n \\ \text{s.t.} \quad & C^0_n + P^D_n C^D_n = W_n L_n + \Pi_n + T_n, \end{aligned} \tag{3.1}$$

where households consume only the final goods from the outside and advanced manufacturing sectors (C^0_n and C^D_n), P^D_n is the price of the advanced manufacturing good, Π_n are profits from domestic firms and T_n are taxes. The outside good is the numéraire.

The outside good is produced using a linear technology: $Q^0_n = A^0_n L^0_n$, where A^0_n is productivity and L^0_n is labor input. We assume that consumption of the numéraire good is always sufficiently large that every country produces the outside good. Because it is freely traded, its price is equalized across countries, normalized to 1, implying that wages $W_n = A^0_n$.

[4]Stackelberg leadership may arise endogenously from commitment through irreversible capacity investment (Dixit, 1980; Maggi, 1996). This is consistent with the rare earth industry, which requires substantial upfront investment in, for example, specialized equipment, environmental compliance systems, and technical expertise. Without such a commitment device, the entry deterrence threat is not credible and the Stackelberg equilibrium is not subgame perfect.

3.3 Downstream Manufacturing Sector

In the manufacturing sector, there is a monopolistically competitive representative firm in each country. They produce using a nested CES technology. The outer CES combines a material composite M_n and labor L_n^D with substitution elasticity η:

$$Q_n^D = A_n^D \left((1 - a_{n,L}^D)^{\frac{1}{\eta}} M_n^{\frac{\eta-1}{\eta}} + (a_{n,L}^D)^{\frac{1}{\eta}} (L_n^D)^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}}, \tag{3.2}$$

where $a_{n,L}^D$ is a cost-share parameter for labor. The inner nest combines the refinery composite q_n and an intermediate input O_n with substitution elasticity $\nu \in [0,1)$:

$$M_n = \left[(a^q)^{\frac{1}{\nu}} q_n^{\frac{\nu-1}{\nu}} + (1 - a^q)^{\frac{1}{\nu}} O_n^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}}, \qquad q_n = \Big(\sum_{f \in \mathcal{F}_n} q_{fn}^{\frac{\theta-1}{\theta}} \Big)^{\frac{\theta}{\theta-1}}, \tag{3.3}$$

where $a^q \in (0,1)$ is the cost-share parameter on refinery and q_n is a CES composite of refinery outputs with elasticity θ.

The associated price indices are

$$P_n^M = \left[a^q \, p_n^{1-\nu} + (1 - a^q) \, (P_n^D)^{1-\nu} \right]^{\frac{1}{1-\nu}}, \qquad p_n = \Big[\sum_{f \in \mathcal{F}_n} p_{fn}^{1-\theta} \Big]^{\frac{1}{1-\theta}}, \tag{3.4}$$

Cost minimization yields the downstream unit cost of input bundles:

$$c_n^D = \left[(1 - a_{n,L}^D)(P_n^M)^{1-\eta} + a_{n,L}^D W_n^{1-\eta} \right]^{\frac{1}{1-\eta}}. \tag{3.5}$$

Each country's varieties are aggregated by a representative final goods producer that produces a non-tradable local composite with a CES technology. This composite can be used as both final consumption and intermediate inputs for the downstream sector:

$$Y_n = \Big[\sum_{m \in \mathcal{N}} (Y_{mn}^D)^{\frac{\delta-1}{\delta}} \Big]^{\frac{\delta}{\delta-1}}, \qquad P_n^D = \Big[\sum_{m \in \mathcal{N}} \left(P_{mn}^D \right)^{1-\delta} \Big]^{\frac{1}{1-\delta}}, \tag{3.6}$$

where δ is the elasticity of substitution and P_n^D is the ideal price index.

Under monopolistic competition, firms charge constant markups over its unit costs: $P_{nm}^D = \frac{\delta}{\delta-1} \frac{\tau_{nm}^D (1+t_{mn}^D) c_n^D}{(1-\varsigma_{nm}^D) A_n^D}$, where ς_{nm}^D is country n's export tax to country m. Demand for country n's variety in country m is $Y_{nm}^D = (\frac{P_{nm}^D}{P_m^D})^{-\delta} Y_m$.

3.4 Upstream Mining Sector

In each country, there is a perfectly competitive representative firm in the mining sector. It has a production function with decreasing returns to scale, capturing the presence of a fixed factor such as land:

$$X_n = A_n^U (L_n^U)^{\chi}, \quad \chi < 1, \tag{3.7}$$

where L_n^U is labor input and χ governs the degree of returns to scale. Decreasing returns to scale imply that the mining sector has convex costs.

The firm's maximization problem is

$$\max_{\{x_{nf}\}} \sum_{f \in \mathcal{F}} \frac{(1 - \varsigma_{nm(f)}^U) P_{nm(f)}^U x_{nf}}{1 + t_{m(f)}^U} - W_n \left(\frac{X_n}{A_n^U} \right)^{\frac{1}{\chi}} \qquad \text{s.t.} \qquad X_n = \sum_{f \in \mathcal{F}} \tau_{nm(f)} x_{nf}, \tag{3.8}$$

where x_{nf} denotes country n's output purchased by firm f in m; $P_{nm(f)}^U$ the associated price charged; and $\varsigma_{nm(f)}^U$ an export tax (if positive) or subsidy (if negative) to m imposed by n. The first-order condition implies that

$$P_{nm(f)}^U = \frac{1 - \varsigma_{nn}^U}{1 - \varsigma_{nm(f)}^U} \tau_{nm(f)}^U (1 + t_{m(f)}^U) P_{nn}^U = \frac{\tau_{nm}^U (1 + t_{m(f)}^U) W_n}{(1 - \varsigma_{nm(f)}^U) \chi A_n^U} \left(\frac{X_n}{A_n^U} \right)^{\frac{1-\chi}{\chi}}. \tag{3.9}$$

Perfect competition implies a no-arbitrage condition: prices are equalized across destinations up to trade costs. However, prices are not separable across destinations due to decreasing returns to scale. Firms earn positive profits of

$$\Pi_n^U = (1 - \chi) P_{nn}^U X_n. \tag{3.10}$$

3.5 Refining Sector

While the quantitative model features positive production by the fringe firm, in this section we impose $z_{\tilde{f}} \to 0$ so that the fringe firm does not produce ($q_{\tilde{f}} \to 0$), allowing us to focus on the interaction between the two large firms. In Appendices B.5 and B.6, we provide general versions of our theoretical results with an active fringe firm.

Each firm in the refinery sector has the following nested CES production function:

$$q_f = z_f \left((a_L^R)^{\frac{1}{\rho}} l_f^{\frac{\rho-1}{\rho}} + (1 - a_L^R)^{\frac{1}{\rho}} x_f^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}}, \qquad x_f = \left(\sum_{m \in \mathcal{N}} x_{mf}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \tag{3.11}$$

where l_f is firm f's labor input, x_f is its mining composite, and z_f is its productivity.

Its input demand for labor and mining composites are

$$l_f = a_L^R \left(\frac{W_{n(f)}}{c_f}\right)^{-\rho} \frac{q_f}{z_f}, \qquad \text{and} \qquad x_{mf} = (1-a_L^R)\left(\frac{P^U_{mn(f)}}{p^U_f}\right)^{-\sigma}\left(\frac{p^U_f}{c_f}\right)^{-\rho}\frac{q_f}{z_f} \tag{3.12}$$

where c_f denotes its unit cost of input bundle and p^U_f the associated mining composite price index:

$$c_f = \left[a_L^R W_{n(f)}^{1-\rho} + (1-a_L^R)(p_f^U)^{1-\rho}\right]^{\frac{1}{1-\rho}}, \qquad p_f^U = \left[\sum_{m\in\mathcal{N}} \left(P^U_{mn(f)}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{3.13}$$

Let $c_{fm} = \frac{(1+t^R_{n(f)m})\tau^R_{n(f)m}}{1-\varsigma^R_{n(f)m}} c_f$ denotes firm f's country m specific unit costs, where $t^R_{n(f)m}$ is tariff rate for imports by country m from country $n(f)$.

Each country's demand for refinery output from firm f, refinery composite, and intermediate composites is:

$$q_{fm} = \left(\frac{p_{fm}}{p_m}\right)^{-\theta} q_m, \qquad q_m = a^q\left(\frac{p_m}{P_m^M}\right)^{-\nu} M_m, \qquad M_m = (1-a^D_{n,L})\left(\frac{P_m^M}{c_m^D}\right)^{-\eta}\frac{Q_m^D}{A_m^D}.$$

Firms are subject to resource constraints: $\sum_{m\in\mathcal{N}} \tau^R_{n(f)m} q_{fm} = q_f$.

Refinery firms have market power and take their effects on sectoral aggregates into account when making decisions. Specifically, when choosing quantity in n, q_{fn}, they take the impact of their own q_{fn} on $\{p_{f'n}, q_{f'n}, p_n, q_n, P_n^M, M_n, O_n, c_m^D\}_{\forall f' \in \{i,e,\tilde{f}\}, \forall n\in\mathcal{N}}$ into account. However, they take as given downstream firms' total expenditures and intermediate input prices $\{E_m^D, P_n^D\}$.

3.5.1 Endogenous Market Structure

Conditions under which the Markup is Well-Defined. Before turning to how market structure is determined, we establish the condition under which the incumbent's markup is well-defined, in the sense that the markup and the monopoly profit remain finite.

Proposition 1. *Suppose the fixed cost F is large enough that the entrant does not enter and the fringe firm does not engage in production $z_{\tilde{f}} \to 0$, so that the incumbent solves the unconstrained monopoly problem. Its profit $\pi(p_m) = (p_m - c_{im}/z_i)\, q_m(p_m)$ attains a maximum at a finite price, and the monopoly markup is finite, if and only if* $\max(\nu, \eta) > 1$.

Proof. See Appendix B.4. □

Proposition 1 states that $\max(\nu, \eta) > 1$ is the key condition for a well-behaved markup. This setting does not rule out complementarity in one of the CES aggregates. It is both necessary and sufficient that one of the two margins be substitutable—either refinery output against the other input within the material bundle, with elasticity ν, or the material bundle against labor, with elasticity η—for the monopoly profit and markup to remain finite and well defined. Because the incumbent's markup under Stackelberg duopoly or deterred entry is always smaller than under unconstrained monopoly, if the unconstrained markup is finite, markups under the two other scenarios also remain finite.

The intuition is as follows. Suppose $\max(\nu, \eta) \leq 1$. Then the unconstrained monopolist's perceived demand $\epsilon_m = \nu(1 - s_m^q) + s_m^q[\eta(1 - s_m^M) + s_m^M]$ is inelastic at every quantity it could choose. Thus, giving up the marginal unit of quantity always raises revenue while saving production cost. The monopolist therefore restricts quantity without bound, $q_m \to 0$, and its price diverges, $p_m \to \infty$. If instead $\max(\nu, \eta) > 1$ holds, perceived demand turns elastic in the left tail, so revenue $p_m q_m$ goes to zero as $q_m \to 0$ and the profit maximum is attained at an interior quantity with a finite markup. For example, suppose $\nu > 1$ and $\eta < 1$. As the monopolist restricts quantity $q_m \to 0$, the refinery composite's expenditure share shrinks $s_m^q \to 0$, and the perceived elasticity converges to $\varepsilon_m \to \nu > 1$, so raising quantity increases profit. As it expands quantity, $q_m \to \infty$, the share approaches to one, $s_m^q \to 1$, and $\varepsilon_m \to \eta(1 - s_m^M) + s_m^M < 1$, so reducing quantity increases profit. The profit maximum therefore lies strictly between these two limits.

Throughout this paper we impose $\max(\nu, \eta) > 1$. In our quantification, $\eta < 1$ and $\nu > 1$, so for the rest of this section we maintain this setting for exposition. The theory itself applies to the remaining cases and accommodates alternative calibrations.

Key Elasticities. Before explaining how market structure is endogenously determined by firms' quantities and entry decisions, we first define key elasticities. Later, we show that firms' markups under different market structures can be expressed as a function of these elasticities and market shares.

First, the firm-level inverse own-demand elasticity in country m, ϵ_{fm}^{-1} and the composite demand elasticity for the refinery sector in country m, ε_m^{-1}, are:

$$\begin{aligned} \epsilon_{fm}^{-1} &\equiv -\frac{\partial \ln p_{fm}}{\partial \ln q_{fm}} = \theta^{-1}(1 - s_{fm}) + \varepsilon_m^{-1} s_{fm} \\ \varepsilon_m^{-1} &\equiv -\frac{\partial \ln p_m}{\partial \ln q_m} = \frac{1}{\nu\,(1 - s_m^q) + s_m^q\left[\eta(1 - s_m^M) + s_m^M\right]}. \end{aligned} \tag{3.14}$$

Here, $s_{fm} \equiv \frac{p_{fm}q_{fm}}{p_m q_m}$ denotes firm f's market share within the refinery composite; $s_n^q \equiv a^q \left(\frac{p_n}{P_n^M}\right)^{1-\nu}$ the refinery composite's share in total material expenditures downstream; and $s_n^M \equiv (1 - a_{n,L}^D)(\frac{P_n^M}{c_n^D})^{1-\eta}$ denotes the downstream cost share of the material composite in unit costs.

The first term $\theta^{-1}(1 - s_{fm})$ captures within-sector reallocation. Higher q_{fm} lowers its own prices, shifting market share away from the rival. The second term $\varepsilon_m^{-1} s_{fm}$ captures the sectoral demand effect. Higher firm f quantity lowers the composite refinery price, which passes through the material composite to downstream costs and output.

Next, we define the inverse cross-elasticity of a rival's price with respect to firm f's quantity:

$$\chi_{fm}^{-1} \equiv -\frac{\partial \ln p_{(-f)m}}{\partial \ln q_{fm}} = \epsilon_{fm}^{-1} - \theta^{-1}. \tag{3.15}$$

It captures how f's expansion affects a rival's price through the refinery aggregates, holding the rival's quantity fixed. Firm f's expansion raises the refinery composite q_m, which lowers the composite price p_m at rate ε_m^{-1} but at the same time shrinks the rival's share of sectoral output, raising its price $p_{(-f)m}$ relative to p_m at rate θ^{-1}.

The final elasticity is ζ_{fm}^{-1}, which captures how firm f's perceived own demand elasticity moves with the composite refinery price, holding each firm's market shares s_{fm} fixed (see Appendix B.3 for derivation):

$$\begin{aligned} \zeta_{fm}^{-1} &\equiv -\frac{\partial \epsilon_{fm}^{-1}}{\partial \ln p_m} = \frac{s_{fm}}{\varepsilon_m}\Gamma_m, \\ \Gamma_m &\equiv \frac{\partial \ln \varepsilon_m}{\partial \ln p_m} = \frac{(\varepsilon_m - \nu)(1-\nu)(1-s_m^q) + (\eta-1)^2 s_m^M (1-s_m^M)(s_m^q)^2}{\varepsilon_m}. \end{aligned} \tag{3.16}$$

ε_m, defined in equation (3.14), is a weighted average of ν, η, and one, with weights $1 - s_m^q$, $s_m^q(1 - s_m^M)$, and $s_m^q s_m^M$. The first and second terms capture the effect of p_m on ε_m through s_m^q and s_m^M, respectively.

Stackelberg Duopoly. Suppose the incumbent decides to allow entry. In this duopoly case the entrant enters and competes with the incumbent, but the incumbent retains an advantage as a Stackelberg leader. It can commit to its quantity first, and the entrant chooses only after observing that commitment.

Profit maximization problems of both the incumbent and the entrant can be expressed as:

$$\max_{\{q_{fm}\}} \sum_{m \in \mathcal{N}} \pi_{fm}(q_{fm}, q_{(-f)m}), \quad f \in \{i, e\}, \tag{3.17}$$

where $\pi_{fm}(q_{fm}, q_{(-f)m}) = \frac{1-\varsigma^R_{n(f)m}}{1+t^R_{n(f)m}} p_{fm} q_{fm} - q_{fm} \frac{c_{fm}}{z_{fm}}$.

The key difference between the two firms is that the entrant takes the incumbent's quantity as given. Let q^{BR}_{em} denote the entrant's best response to the incumbent's quantity:

$$q^{BR}_{em}(q_{im}) = \underset{q_{em}}{\operatorname{argmax}} \left\{ \pi_{em}(q_{im}, q_{em}) \right\}. \tag{3.18}$$

q^{BR}_{em} is implicitly defined by the entrant's first-order condition

$$\frac{\partial \pi_{em}}{\partial q_{em}} = 0. \tag{3.19}$$

The incumbent internalizes its influence on the entrant's best response, so its first-order condition is

$$\frac{\partial \pi_{im}}{\partial q_{im}} + \frac{\partial \pi_{im}}{\partial q_{em}} \frac{d q^{BR}_{em}}{d q_{im}} = 0. \tag{3.20}$$

From the first order conditions in equations (3.19) and (3.20) we derive prices p_{fm} and markups μ^{duo}_{fm} in closed form as functions of market shares and structural parameters, as described in the following proposition.

Proposition 2. *Prices charged by the entrant and incumbent are*

$$p_{em} = \mu^{duo}_{em} \frac{c_{em}}{z_e} = \frac{\epsilon_{em}}{\epsilon_{em} - 1} \frac{c_{em}}{z_e}. \tag{3.21}$$

$$p_{im} = \mu^{duo}_{im} \frac{c_{im}}{z_i} = \frac{\epsilon_{im}}{\epsilon_{im} - 1 + \frac{\chi^{-1}_{em}}{\epsilon^{-1}_{im}} \left[-\frac{d \ln q^{BR}_{em}}{d \ln q_{im}} \right]} \frac{c_{im}}{z_i} \tag{3.22}$$

where

$$\frac{d \ln q^{BR}_{em}}{d \ln q_{im}} = -\frac{\chi^{-1}_{im} + \frac{\theta-1}{\epsilon_{em}-1} \frac{\chi^{-1}_{em}}{\epsilon^{-1}_{em}} \left((1 - s_{em}) \chi^{-1}_{im} - s_{im} \epsilon^{-1}_{im} \right) + \frac{1}{\epsilon_{em}-1} \frac{\zeta^{-1}_{em}}{\epsilon^{-1}_{em}} (s_{im} \epsilon^{-1}_{im} + s_{em} \chi^{-1}_{im})}{\epsilon^{-1}_{em} + \frac{\theta-1}{\epsilon_{em}-1} \frac{\chi^{-1}_{em}}{\epsilon^{-1}_{em}} \left((1 - s_{em}) \epsilon^{-1}_{em} - s_{im} \chi^{-1}_{em} \right) + \frac{1}{\epsilon_{em}-1} \frac{\zeta^{-1}_{em}}{\epsilon^{-1}_{em}} (s_{em} \epsilon^{-1}_{em} + s_{im} \chi^{-1}_{em})} \tag{3.23}$$

Proof. See Appendix B.1. □

The entrant's markup in equation (3.21) takes the similar form as in Atkeson and Burstein (2008), increasing in the firm's own market shares s_{em}. Unlike the entrant, because of the Stackelberg structure, the incumbent's markup in equation (3.22) additionally carries the best-response slope $\frac{d \ln q^{BR}_{em}}{d \ln q_{im}}$ in its denominator.

The best-response slope $\frac{d \ln q^{BR}_{em}}{d \ln q_{im}}$ is the rate at which the entrant must adjust its quantity for its own optimality condition—$p_{em} = \mu_{em}\frac{c_{em}}{z_e}$ in equation (3.21)—to continue to hold as the incumbent varies its quantity. The numerator is the rate at which the incumbent's quantity impacts this condition, and the denominator is the rate at which the entrant's own quantity restores it. The leading terms, χ_{im}^{-1} in the numerator and ϵ_{em}^{-1} in the denominator, are the direct price effects holding the entrant's optimal markup fixed. The remaining terms capture the movement in the entrant's optimal markup itself, due to changes in its within-sector share s_{em} (the terms in $\theta - 1$) and in the composite refinery price p_m (the terms in ζ_{em}^{-1}).

Deterred Entry. In the case of deterred entry, the incumbent solves the following problem:

$$\max_{\{q_{im}\}} \sum_m \pi_{im}(q_{im}) \qquad \text{s.t.} \qquad \sum_m \pi_{em}(q_{im}, q_{em}^{BR}(q_{im})) \leq W_{n(e)}F, \tag{3.24}$$

The incumbent maximizes its profit conditional on blocking entry, by setting quantities high enough that the entrant's profit net of the fixed cost is non-positive, so that entry is deterred. In doing so, it takes into account that its quantity affects the entrant's best response.

The corresponding Lagrangian is

$$\mathcal{L} = \sum_m \pi_{im}(q_{im}) + \Psi\Big\{W_{n(e)}F - \sum_m \pi_{em}(q_{im}, q_{em}^{BR})\Big\}, \tag{3.25}$$

where Ψ is the Lagrange multiplier, with $\Psi > 0$ when the deterrence constraint binds and $\Psi = 0$ otherwise; it is the shadow price of deterring entry. By the envelope theorem, the first-order condition is

$$\frac{\partial \pi_{im}}{\partial q_{im}} - \Psi\frac{\partial \pi_{em}}{\partial q_{im}} = 0. \tag{3.26}$$

Firm i's price p_{im} and markup μ_{im}^{de} are characterized in the following proposition.

Proposition 3. *(i) In the case of deterred entry with a binding deterrence constraint ($\Psi > 0$), the incumbent charges*

$$p_{im} = \mu_{im}^{de}\frac{c_{im}}{z_i} = \frac{\epsilon_{im}\Big(1 + \Psi\frac{\dot{\pi}_{em}}{\pi_{im}}\frac{\dot{\mu}_{em}}{\dot{\mu}_{em}-1}\dot{\chi}_{im}^{-1}\Big)}{\epsilon_{im}\Big(1 + \Psi\frac{\dot{\pi}_{em}}{\pi_{im}}\frac{\dot{\mu}_{em}}{\dot{\mu}_{em}-1}\dot{\chi}_{im}^{-1}\Big) - 1}\frac{c_{im}}{z_i}, \tag{3.27}$$

where a dot above a variable ($\dot{x}$) denotes its off-equilibrium value, evaluated in the subgame in which the entrant enters and plays its best response;

(ii) There exists a threshold $\bar{F}$ such that whenever $F \geq \bar{F}$, the fixed cost becomes too costly for the entrant to enter, the deterrence constraint does not bind ($\Psi = 0$), the incumbent charges the unconstrained markups over unit costs, $p_{im} = \frac{\epsilon_{im}}{\epsilon_{im}-1}\frac{c_{im}}{z_i}$, and the entrant does not enter;

(iii) Conversely, as F falls, deterrence requires ever larger quantities, with markups approaching

the competitive level, and the incumbent's profit under deterrence declines. There exists a threshold $\underline{F} < \bar{F}$ such that for $F \leq \underline{F}$, the profit under deterrence falls below the Stackelberg duopoly profit and the incumbent accommodates entry rather than deterring it.

Proof. See Appendix B.2. □

The off-equilibrium values, denoted with dots in the markup formula in equation (3.27) are the outcomes in the subgame in which the potential entrant enters and competes with the incumbent. Although deterrence means this subgame is never reached, its outcomes affect the incumbent's pricing along the equilibrium path.

In the markup formula, Ψ is the shadow price of the deterrence constraint, $\frac{\dot{\pi}_{em}}{\pi_{im}}$ is the entrant's off-equilibrium profit relative to the incumbent's realized profit, and $\frac{\dot{\mu}_{em}}{\dot{\mu}_{em}-1}\dot{\chi}_{im}^{-1} = -\frac{\partial \ln \dot{\pi}_{em}}{\partial \ln q_{im}}$ is the (absolute) elasticity of the entrant's off-equilibrium profit with respect to the incumbent's quantity, which depends on the cross-elasticity $\dot{\chi}_{im}^{-1}$. Their product measures how far the deterrence constraint pulls the incumbent from its unconstrained optimum. Whenever it is positive, the term in brackets in equation (3.27) exceeds one and the incumbent charges below the unconstrained monopoly markup $\frac{\epsilon_{im}}{\epsilon_{im}-1}$. A more productive entrant raises $\frac{\dot{\pi}_{em}}{\pi_{im}}$ and so tightens the constraint further.

Suppose the fixed cost is sufficiently high. Then the constraint does not bind (i.e., $\Psi = 0$) and the markup collapses to that of an unconstrained monopolist, $\mu_{im}^{de} = \frac{\epsilon_{im}}{\epsilon_{im}-1}$, with ϵ_{im} evaluated at $s_{im} = 1$. Suppose instead that it is instead sufficiently low, that is, F is small. Deterrence then requires prices approaching marginal cost as in perfect competition, since Ψ takes a large value, the markup in equation (3.27) declines toward one, and the incumbent's profit declines toward zero. Before that point is reached, however, the incumbent is better off accommodating entry and earning duopoly profits. These results are summarized in (ii–iii) of Proposition 3.

Finally, although we abstract from fringe firms in propositions 2 and 3, the fringe charges constant markups $\mu = \frac{\theta}{\theta-1}$ if they operate (i.e., $z_{\tilde{f}} > 0$), regardless of US entry.

3.6 Equilibrium

Goods market clearing for the local non-tradable composite, manufacturing, mining, and refinery sectors requires:

$$Y_n = C_n^D + O_n, \qquad \forall n \in \mathcal{N}. \tag{3.28}$$

$$Q_n^D = \sum_{m \in \mathcal{N}} \tau_{nm}^D Y_{nm}^D, \qquad \forall n \in \mathcal{N}. \tag{3.29}$$

$$X_n = \sum_{f \in \mathcal{F}} \tau^U_{nm(f)} x_{nf}, \qquad \forall n \in \mathcal{N}. \tag{3.30}$$

$$q_f = \sum_{m \in \mathcal{N}} \tau^R_{fm} q_{fm}, \qquad \forall f \in \mathcal{F}. \tag{3.31}$$

Under the assumption that the outside good is produced in all countries, labor demanded in the outside sector adjusts to guarantee labor market clearing at $W_n = A^0_n$:

$$L_n = L^0_n + L^U_n + L^D_n + \sum_{f \in \mathcal{F}_n} (l_f + \mathbb{1}_{f=e} F), \qquad \forall n \in \mathcal{N}, \tag{3.32}$$

where $\mathbb{1}_{f=e}$ is an indicator for whether firm f is the entrant.

The government budget is balanced in each country. Each country's net transfer equals revenue collected from import tariffs and export taxes, net of entry subsidy: $\forall n \in \mathcal{N}$,

$$T_n = \sum_{f \in \mathcal{F}_n} \sum_{m \in \mathcal{N}} \frac{(t^U_{mn} + \varsigma^U_{nm}) P^U_{mn} x_{mf}}{1 + t^U_{mn}} + \sum_{f \in \mathcal{F}} \frac{(t^R_{n(f),n} + \varsigma^R_{n(f),n}) p_{fn} q_{fn}}{1 + t^R_{n(f),n}} + \sum_{m \in \mathcal{N}} \frac{(t^D_{mn} + \varsigma^D_{mn}) P^D_{mn} Y^D_{mn}}{1 + t^D_{mn}} \tag{3.33}$$

Most importantly, equilibrium market structure is endogenously determined based on whether the incumbent decides to deter the rival's entrant or not. Comparing profits from the cases of Stackelberg duopoly and deterred entrance, the incumbent chooses whether to deter the entry or not. We formally define the equilibrium below.

Definition 1 (Equilibrium). *Given fundamentals* $\{L_n, A^0_n, A^D_n, A^U_n, z_f, F\}_{n \in \mathcal{N}, f \in \{i,e,\tilde{f}\}}$*, trade costs* $\{\tau^U_{nm}, \tau^R_{nm}, \tau^D_{nm}\}_{n,m \in \mathcal{N}}$*, and policy instruments* $\{t^U_{nm}, t^R_{nm}, t^D_{nm}, \varsigma^U_{nm}, \varsigma^R_{nm}, \varsigma^D_{nm}\}_{n,m \in \mathcal{N}}$*, an equilibrium is a market structure* $\mathcal{F} \in \{\{i, \tilde{f}\}, \{i, e, \tilde{f}\}\}$*, prices* $\{P^D_{nm}, P^U_{nm}, p_{fm}, W_n\}_{n,m \in \mathcal{N}, f \in \mathcal{F}}$*, allocations* $\{C^0_n, C^D_n, O_n, Y_n, Y^D_{nm}, Q^D_n, M_n, L^0_n, L^D_n, L^U_n, l_f, X_n, x_{nf}, q_{fm}\}_{n,m \in \mathcal{N}, f \in \mathcal{F}}$*, and transfers* $\{T_n\}_{n \in \mathcal{N}}$ *such that: (i) households maximize utility; (ii) final-goods aggregators, downstream manufacturers, and mining firms maximize profits; (iii) refining firms play the entry game. The entrant* e *enters if and only if its best-response profits cover the fixed entry cost* $W_{n(e)}F$*; the incumbent, as Stackelberg leader* i*, chooses quantities to maximize profits and deters entry if and only if its profit under deterrence exceeds its profit under the Stackelberg duopoly; and* $\mathcal{F}$ *is the resulting set of operating firms; (iii) goods and labor markets clear; and (iv) each government's budget is balanced.*

3.7 Welfare

Let $\Delta U_n = U_n^b - U_n^c$ denotes welfare changes between the baseline U_n^b and counterfactual U_n^c. With the quasilinear preference, the welfare change can be decomposed into five terms:

$$\Delta U_n = \underbrace{R_n^D \Delta \ln C_n^D}_{\text{Consumer surplus}} + \underbrace{\Delta\Pi_n^U + \Delta\Pi_n^R + \Delta\Pi_n^D}_{\text{Profit shifting: mining + refinery + mfg.}} + \underbrace{\Delta T_n}_{\text{Fiscal transfer}} . \tag{3.34}$$

4. Taking the Model to the Data

In this section, we explain our calibration procedure. There are 70 countries and a rest of the world (ROW). Among these, eleven countries have positive rare earth mining production. Importantly, three countries, China, the US, and Malaysia, can potentially engage in refining. Based on the institutional background, the incumbent refiner is China's. The US potential entrant corresponds to MP Materials. Finally, we model the Malaysian refiner, corresponding to Lynas, an Australian firm that refines in Malaysia, as a fringe firm that does not engage in strategic competition.[5] The reference year for calibration is 2022. Table C.2 reports the set of countries used in our quantitative exercises and their production possibilities in the mining and refining industries. Section C.1 provides details on the calibration procedure and algorithm.

For the calibration, we assume no export taxes, setting $\varsigma_{nm}^D = \varsigma_{nm}^U = \varsigma_{nm}^R = 0$, except for the US refinery subsidy $\varsigma_{\text{US},m}^R$. We assume that the US government provides a common subsidy across all destinations (i.e., $\bar{\varsigma}_{\text{US}}^R = \varsigma_{\text{US},m}^R$ for all m), and $\bar{\varsigma}_{\text{US}}^R$ is calibrated internally.

We calibrate 11 structural parameters $\{\delta, \eta, \theta, \nu, \chi, \rho, \sigma, a^q, a_{n,L}^D, a_L^R, F\}$, geographic fundamentals $\{L_n, A_n^0, A_n^D, A_n^U, \tau_{nm}^U, \tau_{nm}^R, \tau_{nm}^D, z_e, z_i, z_{\tilde{f}}\}$, import tariffs and the US subsidy $\{t_{mn}^D, t_{mn}^U, t_{mn}^R, \bar{\varsigma}_{\text{US}}^R\}$.

4.1 External Calibration

We externally calibrate seven elasticities $\{\delta, \sigma, \theta, \eta, \nu, \rho, \chi\}$ based on previous studies and conduct sensitivity checks to the values of these parameters.

We set the elasticity of substitution for the downstream manufacturing sector to $\delta = 4.3$ following Fontagné et al. (2022). We set the elasticities of substitution across mining varieties

[5] Lynas Rare Earths, an Australian company, mines rare earth concentrate at Mount Weld in Australia but performs the refining stage at the Lynas Advanced Materials Plant in Kuantan, Malaysia. Lynas chose the Malaysian location for its low production and labor costs. The plant began production in 2012 and was for over a decade the only rare earth separation facility of meaningful scale outside China.

and across refining varieties to $\sigma = 11$ and $\theta = 5.8$, respectively, also following Fontagné et al. (2022). Their estimates are at the HS six-digit level. For refining, we also include HS six-digit codes for rare earth-based magnets.[6]

We calibrate the downstream sector's elasticity of substitution between labor and intermediate inputs to $\eta = 0.79$ following Peter et al. (forthcoming).[7] We assign the same value to the refining sector's elasticity of substitution between labor and the mining composite, $\rho = 0.79$. Values of η and ρ below one imply that these inputs are complements, so a higher price of one input reduces demand for the other.

We set the elasticity of substitution between the refined composite and the intermediate input bundle to $\nu = 1.1$, close to Cobb-Douglas. Given our choice of $\eta < 1$, which is consistent with most available estimates, Proposition 1 implies ν must exceed one for the unconstrained markup to be well defined. To the best of our knowledge, there are no previous studies with estimates of this elasticity. We view that weak substitutability between refinery and intermediate input composites is plausible in light of existing estimates of substitution between intermediate inputs that are often weak substitutes or complements.

We set the returns-to-scale parameter in the mining sector to $\chi = 0.7$, implying a supply elasticity of around $\frac{\chi}{1-\chi} = 2.3$. This value is at the upper end of the range of estimated or calibrated values in previous studies.[8] We pick the upper end because raw rare earth mining reserve is quite common across countries.[9]

We take tariffs t_n^D, t_n^U, and t_n^R directly from UNCTAD. Since UNCTAD reports tariffs at the HS six-digit level, we assign the same tariff value to the mining and refining sectors.

Among fundamentals, we externally calibrate labor endowments and trade costs $\{L_n, \tau_{nm}^D, \tau_{nm}^U, \tau_{nm}^R\}$. We obtain employment data from the Penn World Table, adjusted for country-specific human capital from Lee and Lee (2016), to calibrate the labor endowment L_n.

We calibrate the trade costs τ_{nm}^D, τ_{nm}^U, and τ_{nm}^R from a gravity equation in two steps, for the downstream sector and for rare earth mining and refining combined, because standard

[6]HS six-digit codes for rare earths do not separately report mining and refining output. To calculate the mining elasticity, we use HS 261220, 360690, 280530, 284610, and 284690, and take the median across these codes. To calculate the refining elasticity, we add the alloy and magnet codes, HS 720299 and 850511.

[7]Farrokhi (2020) uses $\eta = 0.25$ between labor and refined oil products in the oil downstream sector, consistent with short- and medium-run oil demand elasticities. Boehm et al. (2019) estimate an elasticity between intermediate inputs and primary factors of essentially zero in the short run, using confidential US Census microdata and the Tōhoku earthquake as a natural experiment.

[8]Boer et al. (2024) estimate a supply elasticity of around 2.3 for Lithium using time-series variation. Farrokhi and Lashkaripour (2025) set $\chi = 0.63$. They calculate the ratio of wage bills to value added in the primary energy sector from the GTAP database and find that it averages 0.63.

[9]USGS Mineral Commodity Summaries 2025 report world rare earth reserves above 90 million tons of rare earth oxide equivalent, of which China holds 44 million, Brazil 21 million, India 6.9 million, Australia 5.7 million, Russia 3.8 million, and Vietnam 3.5 million. China accounted for 270,000 of 390,000 tons of actual world mine production in 2024.

Table 1: Calibration Summary

Parameter	Description	Value	Source/Moment
Panel A. Externally Calibrated			
L_n	Labor endowment		Lee and Lee (2016)
A_n^D	Mfg. productivity		Labor productivity, KLEMS
A_n^U	Mining productivity		Rare earth mining production, USGS
A_n^0	Numeraire productivity		ICIO wage bills / labor endowment
τ_{mn}^D	Mfg. trade cost		Gravity estimate
τ_{mn}^U	Mining trade cost		Gravity estimate
τ_{mn}^R	Refinery trade cost		Gravity estimate
t_n^D, t_n^U, t_n^R	Tariffs		UNCTAD
δ	Household mfg. elast. subst.	4.3	Fontagné et al. (2022)
θ	Mfg. elast. subst. refinery variety	5.8	Fontagné et al. (2022)
σ	Refinery elast. subst. mining variety	11.0	Fontagné et al. (2022)
η	Mfg. elast. subst., labor/materials	0.79	Peter et al. (forthcoming)
ρ	Refinery elast. subst., labor/mining composite	0.79	Peter et al. (forthcoming)
ν	Inner elast. subst., refinery/intermediate	1.1	
χ	Mining returns to scale	0.7	Farrokhi and Lashkaripour (2025)
z_i	Refinery leader productivity	1	Normalization
Panel B. Internally Calibrated			
$a_{n,L}^D$	Mfg. labor weight	0.09–1.00	Own-sector intermediate shares, OECD ICIO
a^q	Inner-nest refinery IO coefficient	0.0036	US rare earth imports / downstream VA (0.001)
a_L^R	Refinery labor weight	0.25	CNRE's wage bills / mining input costs (0.61)
z_e	Refinery entrant productivity	0.56	US production by MP Materials (10% of China's)
$z_{\tilde{f}}$	Refinery fringe productivity	0.27	China's 90% share of global refined output
ς_{US}^R	US refinery subsidy	-0.25	Subsidy flows / gross sales of 20%, MP 10-K
F	Fixed entry cost	3.2×10^{-7}	Subsidized US entrant breaks even

Notes. This table provides a summary of the calibration procedure.

HS 6-digit trade data do not allow us to separate the mining and refining sectors. In the first step, we estimate the standard gravity equation using Poisson Pseudo-Maximum Likelihood (PPML) (Santos-Silva and Tenreyro, 2006):

$$X_{nmt} = \exp\left(\beta_1 \ln \text{tariff}_{nmt} + \beta_2 \text{FTA}_{nmt} + \delta_{nm} + \delta_{nt} + \delta_{mt}\right)\epsilon_{nmt}, \tag{4.1}$$

where X_{nmt} denotes trade values from country n to m in year t, and $\ln \text{tariff}_{nmt}$ and FTA_{nmt} are the time-varying tariff and free trade agreement (FTA) indicator. δ_{nm} are the bilateral fixed effects, and δ_{nt} and δ_{mt} are the exporter-year and importer-year fixed effects. ϵ_{nmt} is the error term.

In the second step, we regress $\hat{\delta}_{nm}$ on the standard time-invariant gravity variables $\mathbf{d}_{nm}$, log distance, a common language dummy, and a common colony dummy. We then set $\tau_{nm}^D = \exp\left(-\frac{\mathbf{d}'_{nm}\hat{\beta}_D}{\delta-1}\right)$ from the manufacturing estimates, and construct $\tau_{nm}^U = \exp\left(-\frac{\mathbf{d}'_{nm}\hat{\beta}_M}{\sigma-1}\right)$ and $\tau_{nm}^R = \exp\left(-\frac{\mathbf{d}'_{nm}\hat{\beta}_M}{\theta-1}\right)$ from the combined mining-and-refining estimates. We show the results in Table C.1.

4.2 Internal Calibration

The remaining parameters, fundamentals, and US subsidy are internally calibrated. Although they are jointly calibrated, we explain the moments that are most relevant for each object.

The labor share parameters in downstream production $a^D_{n,L}$ are pinned down by each country's own sector's intermediate shares to value-added, obtained from OECD ICIO. We match own sector's intermediate input shares rather than total input shares because our model's intermediate inputs come from the own sector. The inner-nest rare earth intensity a^q is calibrated to match the ratio of rare earth imports to downstream sector's value added, which is around 0.0001.

Downstream productivity A^D_n is calibrated to match the downstream value-added distribution across countries; A^U_n to match mining production distribution across countries (obtained from USGS); and outside good productivity, which pins down wages $W_n = A^0_n$, is calibrated to match the GDP distribution across countries following Costinot et al. (2016). These distributions identify fundamentals up to a normalization, so we normalize the US to one, $A^D_{\text{US}} = A^U_{\text{US}} = A^0_{\text{US}} = 1$.

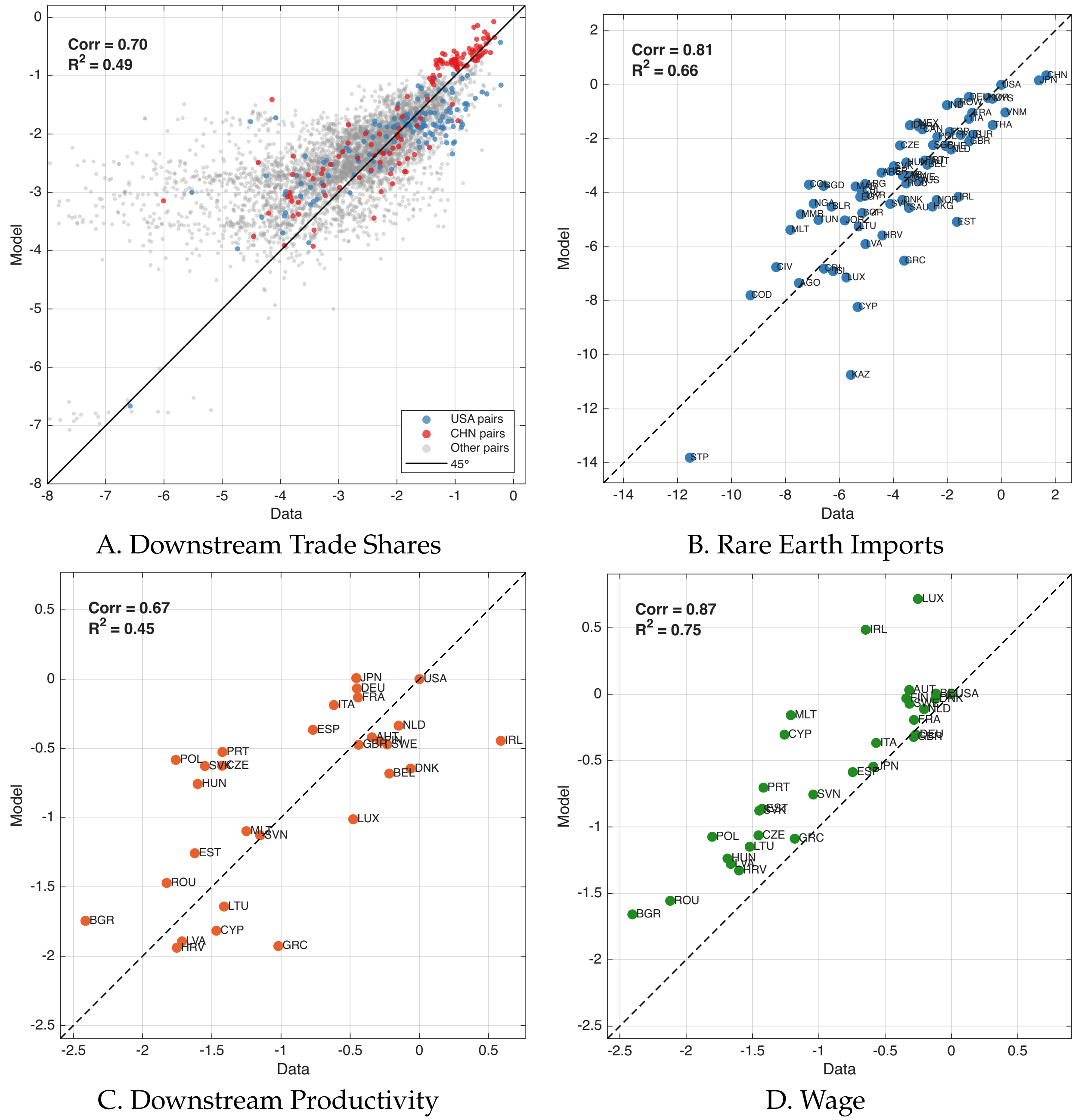
We normalize China's refinery productivity to one, $z_i = 1$. The US entrant's productivity z_e is calibrated to match about 10% of China's total production, $q_e/q_i = 0.1$. This ratio is based on MP Materials' target capacity of approximately 20,000 tonnes of separated rare earth oxides per year at Mountain Pass, measured against China's annual smelting and separation quota of 230,000 to 254,000 tonnes (MP Materials Corp., 2025; USGS, 2024). The fringe firm's productivity $z_{\tilde{f}}$ is calibrated to match China's global production concentration of 90% in Figure 2. We obtain values of $z_e/z_i = 0.56$ and $z_{\tilde{f}}/z_i = 0.27$, implying that the US entrant and the fringe firm have 47% and 73% lower productivity than the Chinese incumbent, respectively.

For the refinery labor weight in the production function a^R_L, we use the ratio of labor costs to expenditure on mining inputs, obtained from the annual reports of China Northern Rare Earth (CNRE) (Figure A.4).[10] CNRE is China's largest rare earth producer, producing about two-thirds of China's rare earth refined output reported by the USGS.

For the US subsidy ξ^R_{US}, we match the recent subsidy program by the Department of Defense. The Department agreed on a purchase price of \$110 per kg. We use this to pin down

[10] Chinese listed firms are required by the PRC Securities Law and the disclosure rules of the China Securities Regulatory Commission (CSRC) to publish an audited annual report, similar to the 10-K filings of US publicly listed firms. These reports are filed on cninfo, the CSRC-designated disclosure portal. We obtain CNRE's wage bills from its consolidated statement of cash flows and its rare earth concentrate purchases from its related-party transaction disclosures.

Figure 3: Estimation Fit: Non-Targeted Moments



Notes. Panel A reports downstream trade shares from the model and the data (BACI). panel B reports rare earth imports, normalized by US imports, from the model and the data. Panel C reports downstream productivity in the model against its empirical counterpart, computed as real value added per worker in downstream manufacturing. Panel D reports calibrated wages in the model against labor compensation per worker. Both data series in Panels C and D are from KLEMS, which covers 33 of the 71 countries in our sample.

entry costs. MP Material's 10-K filings reports revenues obtained from this subsidy flow.[11]

[11] A Form 10-K is the comprehensive annual report that US public companies file with the Securities and Exchange Commission. The subsidy variables appear in several parts of MP Materials' filings. Within the report, Management's Discussion and Analysis (Item 7) reports income from the Price Protection Agreement as a separate line item alongside revenue, as shown in Figure A.3, and describes the terms of the agreement,

We obtain that the firm's subsidy flows to its gross sales is around 20%, which is equivalent to $\bar{\varsigma}^R_{\text{US}} = -0.25$.

We calibrate F to the break-even level for US entry given the observed ratio of subsidy receipts to sales of 20%. This choice is motivated by two observations. First, the US entrant, MP Materials, began operating only after the subsidy program, which requires that entry is profitable with the subsidy. Second, no entry occurred before the subsidy, even after the 2011 restriction, which suggests that unsubsidized entry is unprofitable. Absent direct information on the fixed cost, we choose the largest entry cost consistent with observed entry. Later, we consider alternative calibration targets for F and show that our results remain robust (Figure D.3).

4.3 Estimation Fit

Our calibration takes trade costs from the gravity estimates rather than targeting trade shares or flows directly. Nonetheless, the model delivers a good fit for downstream trade shares across countries and for rare earth imports by each country (Panels A and B of Figure 3). Panels C and D also show that our calibrated downstream productivity A^D_n and wages W_n are sensible. Across the countries covered by the KLEMS dataset which provides external estimates of these objects, both are highly correlated with their counterparts in the data.

5. Quantitative Results

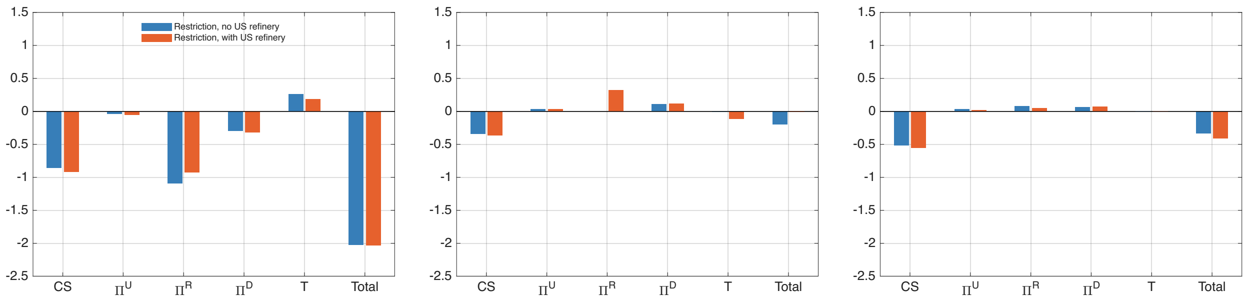
5.1 Evaluating the 2011 Export Restriction

We first evaluate the welfare effects of China's 2011 export restriction. The 2011 restriction is modeled as a common production tax $\bar{\varsigma}^U = \varsigma^U_{\text{CN},m}$ for all $m \in \mathcal{N}$, a domestic production tax in China $\bar{\varsigma}^{R,d} = \varsigma^R_{\text{CN,CN}}$, and an export tax $\bar{\varsigma}^{R,x} = \varsigma^R_{\text{CN},m}$ for all $m \in \mathcal{N} \setminus \{\text{CN}\}$. We calibrate these three wedges to match the mining price spike and the domestic and US import price spikes for refinery output in Figure 4.[12] When backing out these wedges, we use the 2010 mining distribution rather than that of 2020, since mining was more concentrated in China in 2010 and the price spikes we match reflect that distribution. The calibration gives $\bar{\varsigma}^U = 0.586$,

including the \$110 per kilogram price floor. We use these reported flows with the firm's reported sales to construct the ratio of subsidy receipts to sales.

[12]Two of the three price series, Chinese mining output and Chinese refinery output, are ex-works (EXW) prices; the third is the Chinese free-on-board (FOB) price of refinery output shipped to the US. In the model, they correspond to $P^U_{\text{CN,CN}}$, $p_{i,\text{CN}}$, and $\frac{p_{i,\text{US}}}{\tau^R_{\text{CN,US}}(1+t^R_{\text{CN,US}})}$, where the trade cost and the US tariff are divided out because the data are quoted free on board. All three model counterparts are transaction prices, gross of the corresponding wedges $\bar{\varsigma}^U$, $\bar{\varsigma}^{R,d}$, and $\bar{\varsigma}^{R,x}$.

Figure 4: Welfare Effects of the 2011 Export Restriction with and without US Entry



A. China B. US C. Others

Notes. This figure reports decomposition of the welfare effects of the 2011 export restriction with and without US refinery entry. Welfare components (consumer surplus CS, mining profit Π^U, refinery profits Π^R, downstream profits Π^D, and fiscal transfer T) and total welfare effects are reported for China, the US, and other countries (weighted average of countries excluding China and the US) in Panels A, B, and C, respectively.

$\bar{\zeta}^{R,d} = 0.863$, and $\bar{\zeta}^{R,x} = 0.890$, which are equivalent to ad valorem rates of 141%, 628%, and 806%. A much larger rate is required for mining to rationalize its price increase despite a fall in demand caused by the reduction in refinery output.

Under the calibrated values of the US subsidy $\bar{\zeta}^{R}_{\text{US}}$ and the fixed entry cost F, the US refiner enters in the 2011 restriction counterfactual. The calibrated fixed cost, however, is based on MP Materials' entry and production post 2020. In 2010, a year before the restriction was imposed, Western policymakers did not anticipate the shock, and the fixed cost could have been larger due to regulatory and environmental costs. To quantify the importance of US entry under such a shock, we therefore treat US entry as exogenous and compare the welfare effects of the restriction with US entry, at the calibrated fixed cost and subsidy, against those without US entry, obtained by imposing a sufficiently high F.

Mining productivity is held at its 2020 production-share implied level, so welfare effects should be read as conditional on the 2020 mining distribution, with and without a US refinery. We later consider the 2010 mining distribution and supply chain diversification strategy through mining versus refinery.

Figure 4 reports the welfare effects by component for China, the US, and the remaining countries (Others), excluding the two. For Others, welfare effects are obtained as a weighted average across countries other than China and the US, with weights given by downstream expenditure R^D_n. Without US entry, the restriction is even welfare-reducing for China, because the higher taxes reduce consumer surplus $R^D_n \ln C^D_n$ and refinery profits. However, these losses are partially offset by an increase in the fiscal transfer T_n due to the higher taxes, and in downstream profit Π^D_n. China's downstream profit increases because refinery export taxes exceed domestic taxes, making China's downstream production costs cheaper than those of

Table 2: Welfare Effects of the 2011 Restriction by Policy Instrument (%)

	No US entry			US entry with subsidy		
	China	US	Others	China	US	Others
Full 2011 bundle	−2.027	−0.198	−0.333	−1.929	0.029	−0.299
Mining tax	−0.222	−0.032	−0.072	−0.119	0.014	0.041
Domestic production tax	−1.431	−0.054	−0.024	−1.509	0.070	0.082
Export tax	−0.425	−0.136	−0.272	−0.122	0.001	−0.222

Notes. This table reports the total welfare effects of the 2011 export restriction with and without US refinery entry for each policy instrument: China's domestic refinery tax, export refinery tax, and mining tax.

other countries and shifting profits toward China. Both the US and Others experience welfare losses, mostly attributable to decreases in consumer surplus.

With US entry, the restriction results in a much smaller welfare loss for the US, by 94.3%. For China and Others, by contrast, US entry makes the restriction slightly more costly, by 0.3% and 22.3% respectively. For China, US entry cuts the loss in refinery profits of downstream expenditure, but this is offset by a smaller fiscal transfer, as taxed export volumes shrink, and by larger losses in consumer surplus and downstream profits, leaving China's total effect essentially unchanged. For Others, US entry erodes the refinery profits that their producers gain from the restriction, making their welfare losses larger.

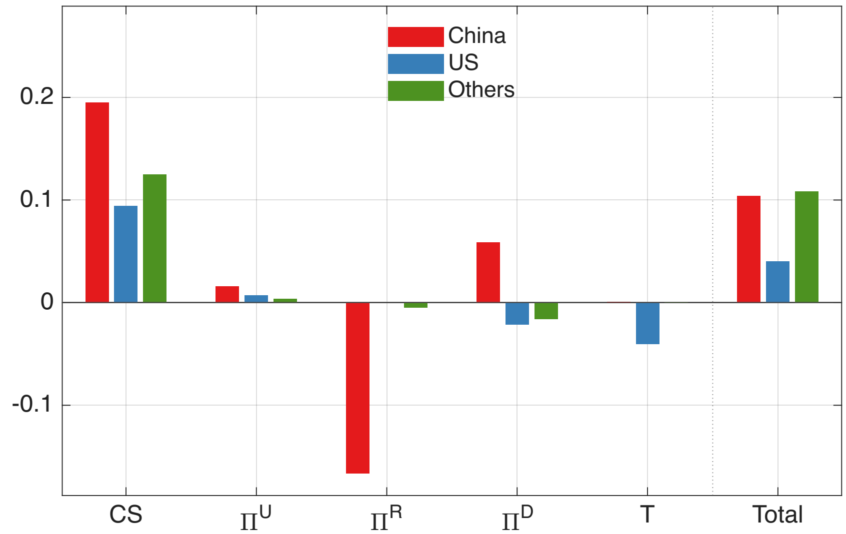
Table 2 reports the welfare effects of each instrument separately. Without US entry, China's domestic refinery tax generates the largest welfare loss for China itself, while the export tax imposes the largest losses on the US and on the other countries. Under US entry, however, the US insulates itself from China's policy instruments, with small gains from the mining and domestic refinery taxes and no loss from the export tax.

5.2 US Entry Subsidy

Next, we evaluate welfare effects of the calibrated US subsidy rate of 25%. Because the fixed cost is calibrated such that this 25% subsidy makes the US refinery enter at the margin, when removing US subsidies in the counterfactual, the US refinery does not enter.

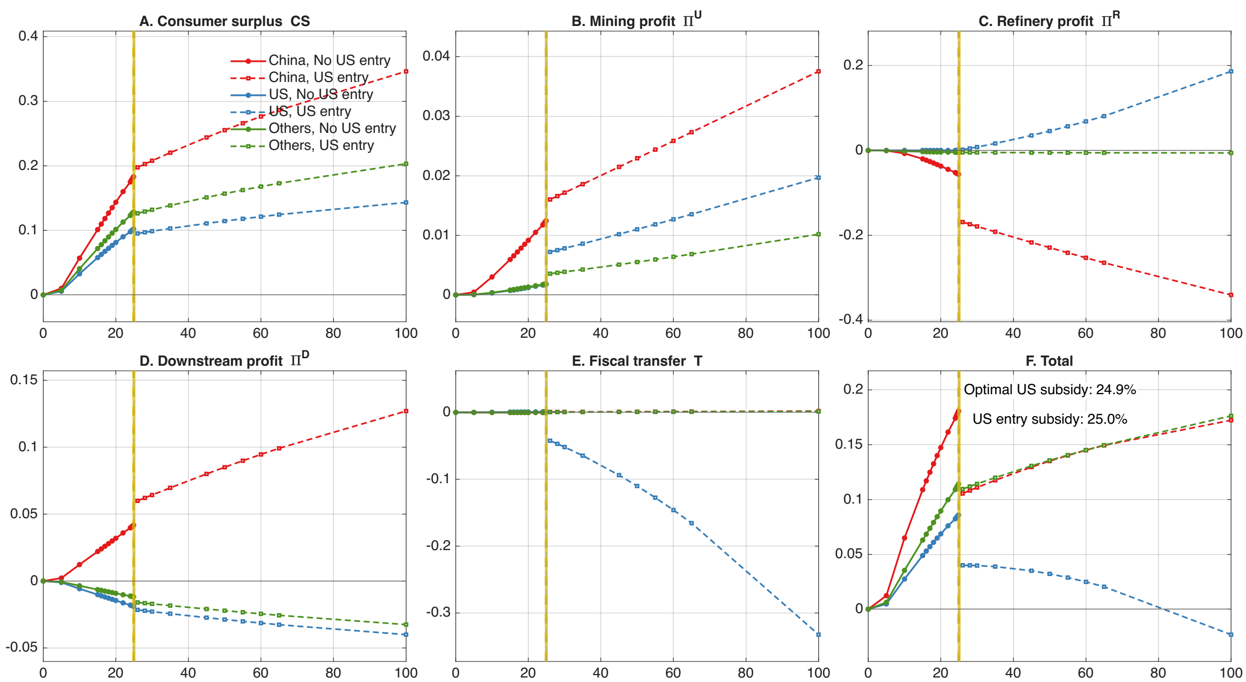
Figure 5 reports each country's changes in welfare by component between the baseline and the counterfactual without US subsidies. Compared to the no-subsidy case, the subsidy increases the welfare of China, the US, and Others, mostly through the consumer surplus margin, as the US entry lowers downstream production costs. The consumer surplus gain is largest for China, and downstream profits shift toward China, because China's intermediate input intensity is larger than the others', so it gains the most from the lower prices due to

Figure 5: Welfare Effects of US Subsidy



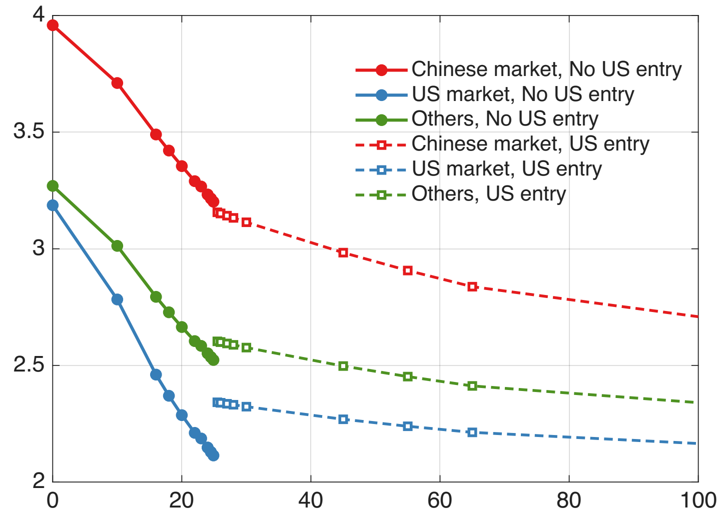
Notes. This figure reports decomposition of the welfare effects due to the US subsidy. Welfare components (consumer surplus CS, mining profit Π^U, refinery profits Π^R, downstream profits Π^D, and fiscal transfer T) and total welfare effects are reported for China, the US, and ROW (weighted average of countries excluding China and the US).

Figure 6: Welfare Paths over US Subsidy Rates



Notes. This figure reports paths of the welfare changes due to the US subsidy. Welfare components (consumer surplus CS, mining profit Π^U, refinery profits Π^R, downstream profits Π^D, and fiscal transfer T) and total welfare effects are reported for China, the US, and Others (weighted average of countries excluding China and the US). X-axis denotes for US subsidy rates $-\bar{\zeta}^R_{\mathrm{US}}$, and y-axis denotes for welfare changes relative to downstream sector expenditure R^D_n. At the rate of 25%, the US entry occurs.

Figure 7: Chinese Refinery's Markups: Deterred Entry vs. Stackelberg Duopoly

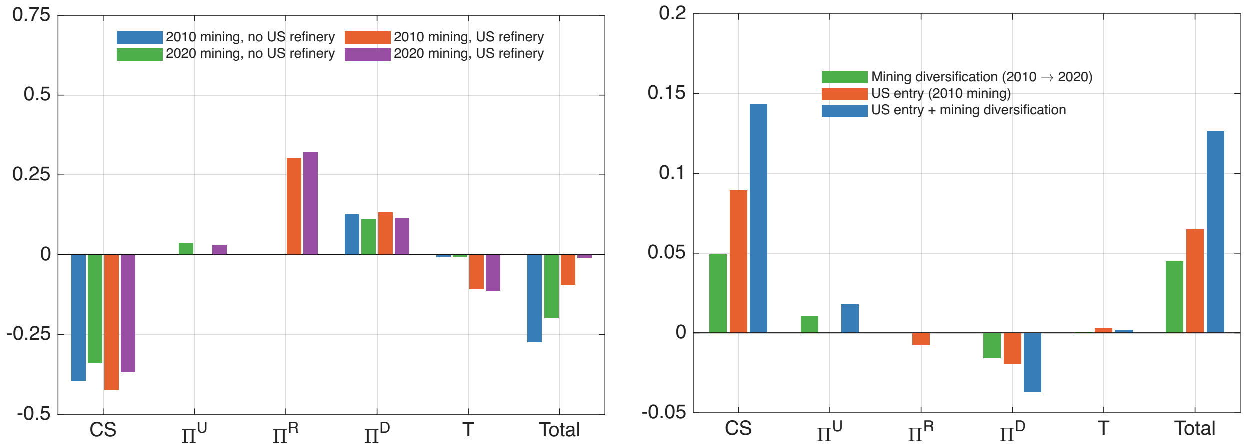


Notes. This figure reports the Chinese refinery's markups in Chinese market, US market, and other markets (R_n^D-Weighted-average across countries, excluding the two), over different world and US export taxes, in Panels A and B, respectively.

US entry. China also gains in mining profits. However, these increases in downstream and mining profits cannot cover the refinery profit loss.

Figure 6 reports the paths of welfare changes across different US subsidy rates. The US optimum is achieved at the rate just before actual entry occurs. The reason is that at that threshold, low US subsidies induce the Chinese incumbent to charge lower markups in order to deter entry. Just beyond that threshold, US entry occurs and the Chinese incumbent charges higher markups and increas its prices in the US and Others markets, even though it now competes as a Stackelberg duopolist there. This is shown in Figure 7. The figure reports the Chinese refinery's markups in the Chinese, US and Others markets, where the Others' markup computed as the R_n^D-weighted average across all countries excluding the two. Once the US refinery enters beyond the subsidy rate of 25%, the Chinese refinery raises its markups in the US and Others markets, while increasing it in the Chinese market. The increase is the largest in the US market. The reason is that the Chinese refinery limit-prices most aggressively in the US market, where competition with the potential entrant is most severe (captured by $\dot{\chi}_{im}^{-1}$ in equation (3.27)), holding its markup there furthest below unconstrained level. The Chinese market is the exception because the incumbent was never limit-pricing in its home market as aggressively, and entry, by placing an actual competitor in its home market, decreases its market share and pulls its home markup down. As subsidy rates increase further, the US refinery gains market share while the Chinese refinery loses, which erodes the Chinese refinery's markups at higher subsidy rates. Higher US subsidies beyond the optimum raise US profits in mining and refining, as well as consumer surplus.

Figure 8: US Supply Chain Diversification, Mining versus Refining



A. Welfare Loss from the 2011 Restriction B. Gains from Diversification in Normal Times

Notes. This figure reports decomposition of the welfare effects of US supply chain diversification in mining and in refining, for the US. Panel A reports the effects of China's 2011 export restriction under four combinations of the mining distribution and US refinery entry. Panel B reports the gains from mining diversification, from US refinery entry, and from the two together in normal times. US refinery entry is exogenous in both panels. In Panel B, the subsidy cost is not subtracted, as we do not model any subsidy cost for mining diversification.

However, declines in downstream profits and a deteriorating fiscal transfer make the net welfare effect smaller than at the optimum.

5.3 US Supply Chain Diversification Strategy, Mining versus Refining

In this subsection, we explore US supply chain diversification strategies in mining versus refining. As in the previous 2011 export restriction counterfactual, we set US refinery entry as exogenous. Mining diversification is modeled as an exogenous change in the productivity distribution, fitted to the change in mining production shares from 2010 to 2020. Figure D.1 shows the backed-out productivity and production shares in 2010 and 2020.

We consider two counterfactuals. First, we evaluate China's 2011 export restriction under different diversification scenarios. We evaluate the 2011 restriction's effects under four possible combinations: (i) the 2010 mining distribution without US refinery entry; (ii) the 2020 mining distribution without US refinery entry; (iii) 2010 mining with US refinery entry; and (iv) 2020 mining with US refinery entry. By construction, cases (ii) and (iv) coincide with the welfare results reported in Figure 4.

Panel A of Figure 8 reports the results. Under the 2010 mining distribution without a US refinery, the restriction decreases US welfare by 0.27%. With mining diversification, this welfare loss becomes 0.20%. US refinery entry makes the US more resilient to such a restriction. With US refinery entry, even under the 2010 mining distribution, the welfare loss becomes 0.09%. Finally, with both mining and refining diversification, the welfare loss becomes 0.01%, close to zero, as lower mining costs in the US make the US refinery expand more effectively during the restriction. These results suggest that refinery diversification makes the US more resilient than mining diversification, and that the combination of these two diversification strategies brings complementarity gains.

In Panel B, we evaluate the gains from each diversification strategy in normal times, absent any export restriction. When we compare the gains from US refinery entry with those from mining diversification, we do not subtract the subsidy cost, because we do not model any subsidy cost for mining diversification. Mining diversification alone raises US welfare by 0.04%, and US refinery entry at the 2010 mining distribution raises it by 0.07%, net of the entry cost. Implementing both together raises US welfare by 0.13%, which exceeds the sum of the two separate gains. Figure D.2 reports the effects for China and Others. The other countries also gain more from US refinery entry than from mining diversification.

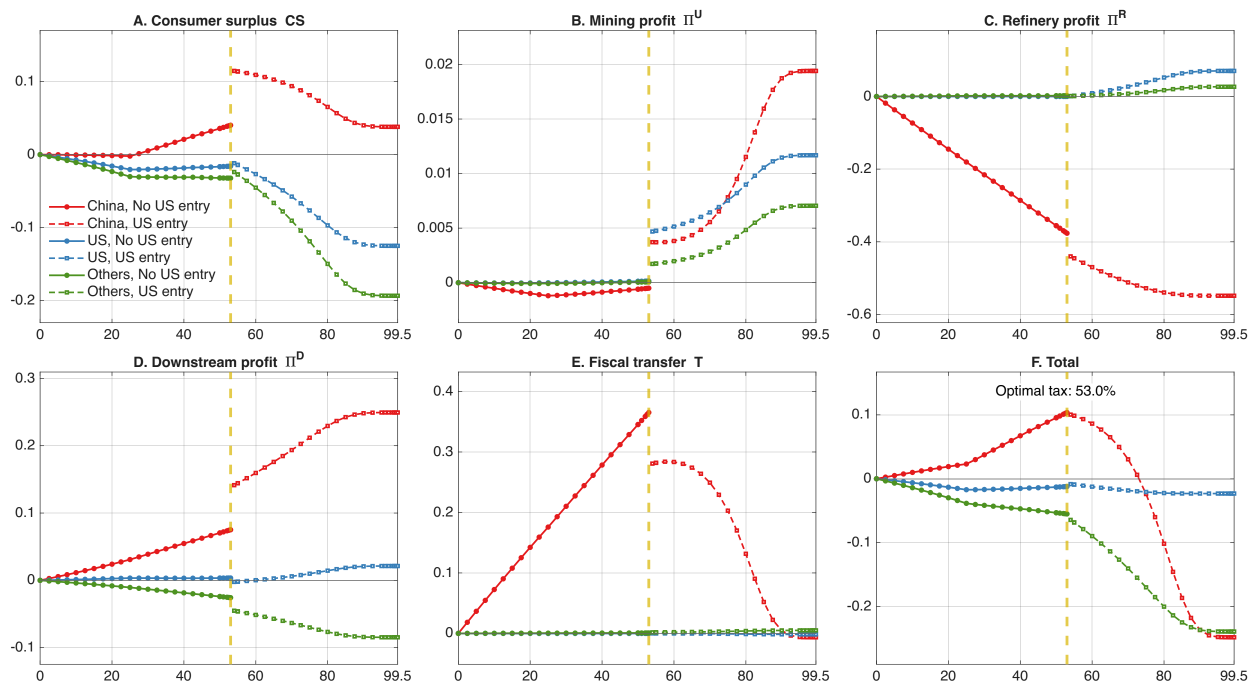
5.4 China's Export Tax

Next, we examine China's export tax against the world: $\varsigma^R_{\mathrm{CN},m} = \bar{\varsigma}^R, \forall m \in \mathcal{N} \setminus \{\mathrm{CN}\}$. For this exercise, we set the US subsidy to zero, so the US refinery does not enter initially, but the higher export tax can induce US entry.

Figure 9 reports the results. Beyond a threshold of around 53%, the US refinery enters. Up to this threshold, higher export taxes raise China's consumer surplus while lowering that of the US and Others. The tax diverts the Chinese refinery's sales toward the domestic market, and the quantity expansion required to deter entry amplifies this diversion, reducing domestic refined prices while raising export prices. This price divergence is what redistributes consumer surplus toward China. US entry changes the markup structure asymmetrically. The Chinese refinery had compressed its markups in the contested export markets to keep the entrant out, so once entry occurs its US-market markup jumps up, while in the far less contested Chinese market entry brings actual competition and the domestic markup falls as in the subsidy counterfactual (Panel A of Figure 11). Entry therefore reduces the consumer surplus of the US and Others, while amplifying the gains of Chinese consumers, whose surplus doubles at the threshold.

China's downstream profits also rise with the export tax, with a discrete upward jump at US entry. The gradual increase reflects the tax raising downstream production costs in other countries relative to China, shifting downstream profits toward China. The jump at entry occurs because the US entrant's additional supply lowers China's downstream input costs and China's intermediate input intensity is higher, so it enjoys larger input cost reduction

Figure 9: Welfare Paths over China's World Refinery Export Tax



Notes. This figure reports paths of the welfare changes due to the China's world export tax. Welfare components (consumer surplus CS, mining profit Π^U, refinery profits Π^R, downstream profits Π^D, and fiscal transfer T) and total welfare effects are reported for China, the US, and Others (weighted average of countries excluding China and the US). X-axis denotes for ad-valorem export tax rates, and y-axis denotes for welfare changes relative to downstream sector expenditure R_n^D.

than other countries.

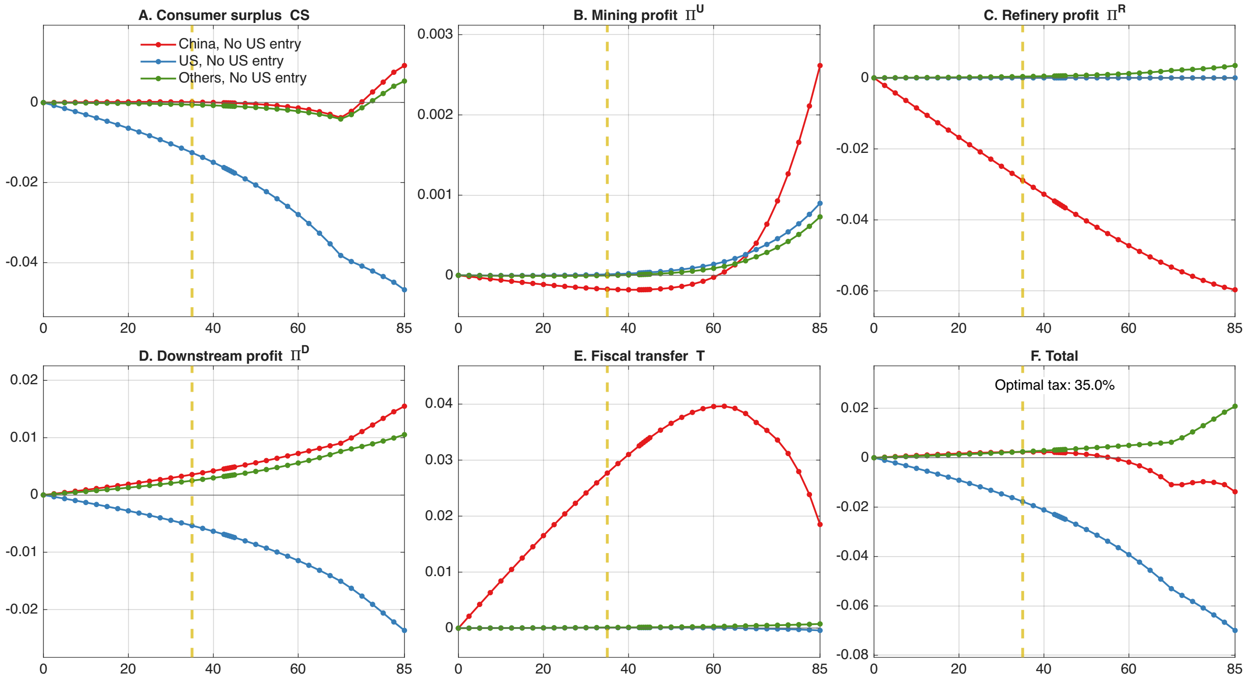
The world tax also raises China's fiscal transfer up to the entry threshold. Beyond it, higher export taxes reduce the transfer, as foreign downstream producers substitute toward the US entrant and the taxed trade volume collapses. While the economic logic resembles a standard Laffer curve, in our model the elasticity of the tax base changes endogenously with the market structure and firm markups.

China's optimal world tax is an export tax of about 53% (an epsilon below the entry threshold), equivalent to an ad valorem rate of 113%. At the optimum, China's welfare gain is 0.10% of its downstream revenue. Beyond the threshold, US entry erodes China's export tax revenue, and its net welfare gain shrinks, turning negative at higher rates. For the US, the net welfare effects remain flat around the threshold, because the positive welfare gain from entry is roughly offset by the fixed entry cost.

Next, we consider a scenario in which China imposes an export tax only on the US. Figure 10 reports the results. Unlike the world export tax, the US-specific tax cannot induce US entry without subsidies.[13] A higher US-specific tax reduces US consumer surplus, while Others

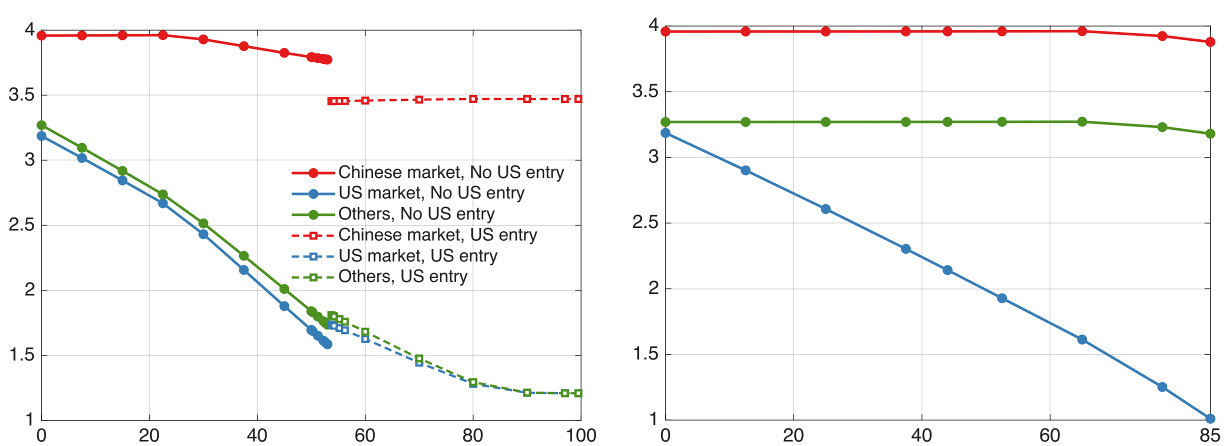
[13]For graphical clarity, we report US tax rates up to 85%. We solve the model at prohibitively higher rates

Figure 10: Welfare Paths over China's USA Refinery Export Tax



Notes. This figure reports paths of the welfare changes due to the China's export tax to the US. Welfare components (consumer surplus CS, mining profit Π^U, refinery profits Π^R, downstream profits Π^D, and fiscal transfer T) and total welfare effects are reported for China, the US, and Others (weighted average of countries excluding China and the US). X-axis denotes for ad-valorem export tax rates, and y-axis denotes for welfare changes relative to downstream sector expenditure R_n^D.

Figure 11: Chinese Refinery Markups over Export Taxes



A. World Export Tax B. USA Export Tax

Notes. This figure reports the Chinese refinery's markups in Chinese market, US market, and other markets (R_n^D-Weighted-average across countries, excluding the two), over different world and US export taxes, in Panels A and B, respectively.

Table 3: Robustness. Alternative Parameters and Scenarios

Robustness	US Subsidy	
	ΔUS welfare	ΔChina welfare
Baseline	0.086	0.181
$\delta = 2$ (Boehm et al., 2023)	0.178	0.237
$\theta = \sigma = 11$ (Fontagné et al., 2022)	0.082	0.169
$\eta = 0$ (Boehm et al., 2019)	0.081	0.114
$\eta = 0.25$ (Farrokhi, 2020)	0.082	0.135
$\rho = 0$ (Boehm et al., 2019)	0.081	0.168
$\rho = 0.25$ (Farrokhi, 2020)	0.081	0.168
$\chi = 1$	0.088	0.205
$F = 0.9 \times F^{\text{baseline}}$	0.097	0.196
$F = 0.5 \times F^{\text{baseline}}$	0.091	0.169
$0.9 \times \frac{a^q}{1-a^q}$ (Alfaro et al., 2025)	0.078	0.164
No fringe firm	0.077	0.208
Constant markup	−0.002	−0.044
Variable markup, no deterred entry (Atkeson and Burstein, 2008)	0.004	0.011

Notes. This table reports the robustness checks to alternative parameter values and scenarios. The table reports changes in welfare effects with no US subsidy (baseline) and US subsidy (counterfactual). For each alternative parameter and scenario, the parameters and fundamentals are internally re-calibrated.

gain throughout and China gains only at low rates. Higher tax rates also shift downstream profits from the US toward China and Others. China's fiscal transfer increases initially, peaking at a tax rate of around 60%, and declines sharply beyond that point as the taxed trade volume collapses. Both the collapse of China's fiscal transfer and the steep fall in US consumer surplus occur over the same interval. At low tax rates, China absorbs the tax by compressing its markup in the US market. Its price there begins at more than three times marginal cost, so there is substantial markup to give up. Pass-through to US consumers is therefore incomplete, bilateral volumes hold up, and revenue grows. As the markup is progressively spent, pass-through rises and volumes fall faster, until by a tax rate of around 85% the markup has been squeezed down to one and the Chinese refinery sells to the US at marginal cost (Panel B of Figure 11). From that point, every additional point of tax passes fully into US prices.

China's optimal US-specific export tax is 35%, which yields a modest net welfare gain of 0.002% of its downstream revenue. Notably, the bilateral instrument is far more effective as a weapon than as a source of gains. The US welfare loss that China inflicts at this optimum, 0.018%, is roughly eight times larger than China's own gain.

and confirm numerically that the entrant's profit converges to a level below the calibrated entry cost, so entry never occurs.

5.5 Sensitivity and Robustness Checks

We consider alternative parameter values as robustness checks, and report the welfare effects of the US subsidy in Table 3. We consider $\delta = 2$ (Boehm et al., 2023), $\theta = \sigma = 11$ (the upper range of rare earth-related elasticities from Fontagné et al. (2022)), $\eta = 0$ or $\rho = 0$ (Boehm et al., 2019), $\eta = 0.25$ or $\rho = 0.25$ (Farrokhi, 2020), and $\chi = 1$ (constant returns to scale in mining). Instead of calibrating the fixed entry cost F to the break-even level for the subsidized US entrant, we also consider alternative values of F between 90% and 50% of that level. Across these alternative values, our results remain similar.

To better understand the model's mechanism, we also consider alternative scenarios. Alfaro et al. (2025) find evidence of directed technological change that substitutes away from rare earth usage in production after the 2011 restriction. We implement a 10% reduction in the effective rare earth weight, which corresponds to setting $\frac{a^q}{1-a^q} = 0.9\frac{a^{q,(b)}}{1-a^{q,(b)}}$, where $a^{q,(b)}$ denotes the baseline calibrated value. Under this alternative, the gains to both the US and China from the US subsidy fall by about 10%. Without fringe firms, the results remain robust although the US gains decrease by about 10%.

Lastly, we consider two alternative market structures. In the first, all firms charge constant markups, without engaging in oligopolistic pricing or strategic competition. In the second, we allow for oligopolistic Cournot pricing as in Atkeson and Burstein (2008), but firms do not engage in Stackelberg competition and the incumbent does not deter the US entrant. In both cases, the US gain from its subsidy is close to zero, at -0.002 and 0.004 respectively, suggesting that deterred entry is the key mechanism behind sizable gains from the US subsidy.

6. Conclusion

How does a dominant incumbent's strategic pricing shape the global supply chain for a critical mineral, and what policies can counteract it? We develop a quantifiable multi-country general equilibrium model of three vertically linked sectors (mining, refining, and advanced manufacturing) in which market structure in refining is endogenous. A Chinese incumbent moves first and chooses whether to commit to quantities large enough to keep a Western entrant out, and the resulting configuration, monopoly or Stackelberg duopoly, follows from the interaction of the incumbent's conduct, the entrant's fixed cost, and trade frictions along the chain.

Using the model and novel data we show that the 2011 restriction was costly for all regions, but a Western refiner would have absorbed the US loss almost entirely. The US entry subsidy implied by the Department of Defense price floor raises welfare everywhere, and by more in China than in the US, because entry lowers refined prices and China's downstream sector is more input intensive than the US. And China's optimal export tax is pinned down by the entry margin rather than by revenue considerations: the optimal world tax sits just below the rate that would trigger the entry of the US refiner, and the optimal bilateral tax on the US inflicts about eight times more damage than it generates in gains.

In terms of policy implications, we show that most of the return to supporting a Western refiner comes from disciplining the incumbent's markup rather than from the entrant's own output: US welfare peaks just short of actual entry, where the incumbent prices to deter. Second, the gains from Western subsidies are substantially shared, including with China, so unilateral subsidies are unlikely to be calibrated efficiently from a global standpoint.

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ONLINE APPENDIX
(NOT FOR PUBLICATION)

A. Appendix: Data

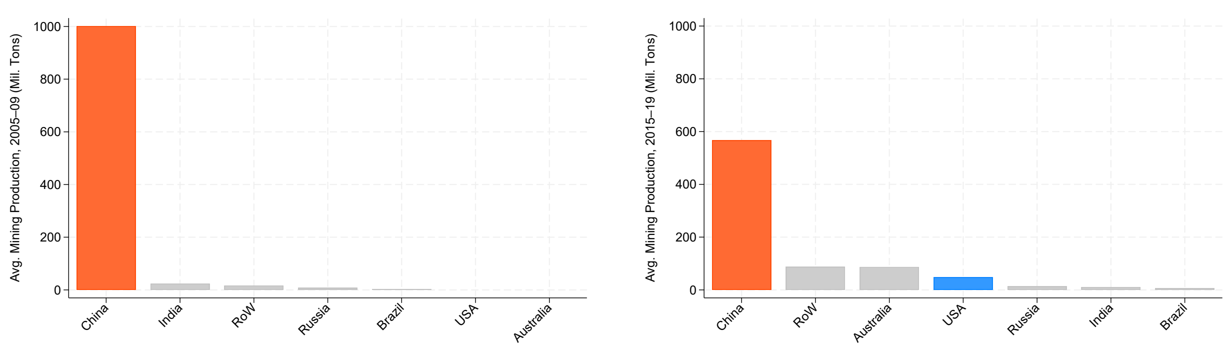
A.1 Data Sources for Global Production Concentration

Our data for the global production concentration shares in Panel B of Figure 2, denoted by blue dots, come from multiple sources. China's share of US imports of refined rare earth products is computed from USGS import data as reported in the rare earths chapters of the *Minerals Yearbook*. We classify a product as refined when its six-digit heading covers rare earth metals or separated rare earth compounds (HS six-digit codes 280530, 284610, and 284690), and we compute China's share of total import quantity in each year.

The external estimates of global production shares are point observations collected from public sources and government reports. U.S. Government Accountability Office (2010) reports China's share of separated rare earth oxides at 97 percent in 2010. After 2015, we record 90% in 2019 and 2021 and 92% and 91% in 2023 and 2024, from successive editions of the IEA *Global Critical Minerals Outlook* (IEA, 2024), and 90% of processing capacity in 2020 from Andrews-Speed and Hove (2023).

A.2 Additional Tables and Figures

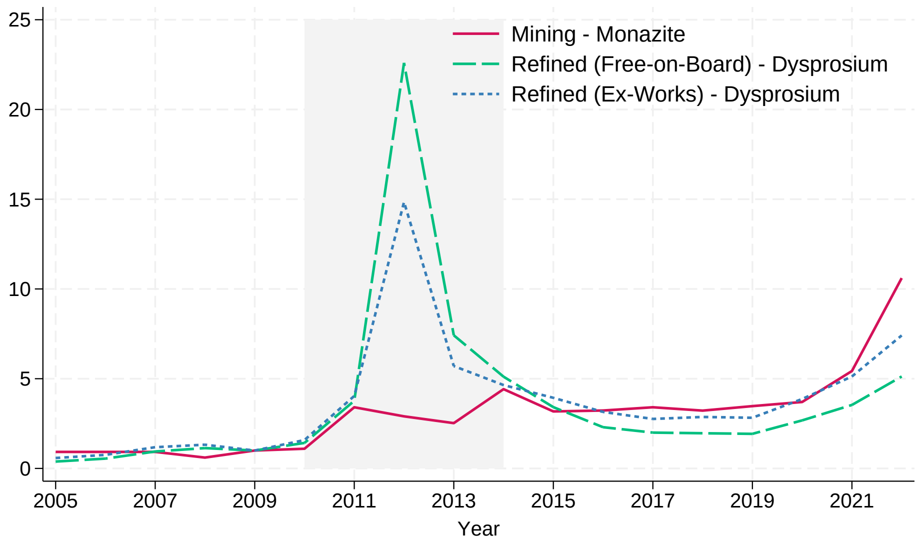
Figure A.1: Average Mining Production by Country



A Pre-export restriction 2001-2009

B. Post-export-restriction 2015-2019

Figure A.2: Robustness. China's 2011 Rare Earth Export Restriction and Dyprosium Prices



Notes. This figure plots three prices of rare earth output: raw mining rare earth output (Monazite), free-on-board prices at Chinese ports and factory gate prices of refined rare earth output (Dyprosium).

Figure A.3: MP Materials' Subsidy Amounts from the Price Protection Agreement

Price protection agreement income

As discussed in the "Recent Developments" section above, the PPA for our NdPr Products commenced on October 1, 2025; given market prices for NdPr Products in the fourth quarter, we recognized price protection agreement income ("PPA Income") based on the right to receive cash from the DoW for the difference between $110 per kg and the Benchmark Quarterly Average Volume Weighted Price (as defined in the PPA) for the NdPr Products produced at Mountain Pass that were sold or produced and stockpiled during the fourth quarter of 2025. The majority of the PPA Income recognized during the fourth quarter of 2025 pertained to sales to third parties and NdPr Products produced and stockpiled.

	For the year ended December 31,			**$ Change**		**% Change**	
(in thousands)	**2025**	**2024**	**2023**	**2025 vs. 2024**	**2024 vs. 2023**	**2025 vs. 2024**	**2024 vs. 2023**
Price protection agreement income	$ 51,016	$ —	$ —	$ 51,016	$ —	N/M	N/M

N/M = Not meaningful.

Notes. This is part of MP Materials' Annual Report on Form 10-K for fiscal year 2025 (p. 90), which describes the subsidy amounts it received from the Price Protection Agreement with the Department of Defense. Highlighting added.

Figure A.4: Refinery Wage Bill and Mining Input Costs, China Northern Rare Earth 2020

A. Rare earth concentrate purchased from Baotou Steel Union (RMB)

关联方	关联交易内容	本期发生额	上期发生额
内蒙古包钢钢联股份有限公司	供水	4, 138, 686. 93	1, 723. 65
内蒙古包钢钢联股份有限公司	供电	19, 864, 352. 07	17, 589, 748. 50
包头钢铁（集团）有限责任公司及其下属公司	加工费	15, 986, 532. 03	
内蒙古包钢钢联股份有限公司	稀土精矿	1, 693, 429, 252. 20	2, 055, 201, 823. 08

B. Cash paid to and on behalf of employees (RMB)

经营活动现金流入小计		19, 800, 893, 703. 33	17, 105, 004, 860. 85
购买商品、接受劳务支付的现金		17, 367, 212, 641. 21	14, 389, 679, 958. 66
支付给职工及为职工支付的现金		1, 033, 249, 355. 49	985, 590, 995. 05
支付的各项税费		576, 575, 610. 32	568, 639, 106. 96
支付其他与经营活动有关的现金	七、78	245, 603, 948. 34	273, 208, 060. 83

Notes. This figure reproduces excerpts from the 2020 annual report of China Northern Rare Earth, ticker 600111, filed on cninfo. Panel A is the related-party transactions table, which reports rare earth concentrate purchased from Inner Mongolia Baotou Steel Union. Panel B is the consolidated statement of cash flows, which reports cash paid to employees.

B. Appendix: Model

B.1 Derivation of ϵ_{fm}^{-1} in Equation (3.14)

In this subsection, we derive the expression for ϵ_{fm}^{-1} in equation (3.14). Note that refinery firms take the wage W_m, downstream expenditure E_m, and the local final goods price P_m^D as given, while they internalize the equilibrium adjustment of Q_m^D.

Totally differentiating the firm-level inverse demand, $p_{fm} = (\frac{q_{fm}}{q_m})^{-\frac{1}{\theta}} p_m$, with respect to $\ln q_{fm}$, we obtain that

$$\begin{aligned} -\frac{\partial \ln p_{fm}}{\partial \ln q_{fm}} &= \frac{1}{\theta} - \frac{1}{\theta}\frac{\partial \ln q_m}{\partial \ln q_{fm}} - \frac{\partial \ln p_m}{\partial \ln q_m}\frac{\partial \ln q_m}{\partial \ln q_{fm}} \\ &= \theta^{-1}(1 - s_{fm}) + \varepsilon_m^{-1} s_{fm} \end{aligned} \tag{B.1}$$

The first term in the right hand side of the first equality is the direct effect from changing firm f's own quantity, the second is the indirect effect through the composite quantity q_m, and the third is the response of the composite price p_m due to changes in q_m. The second equality comes from that $\frac{\partial \ln q_m}{\partial \ln q_{fm}}$, obtained from totally differentiat ing $q_m^{\frac{\theta-1}{\theta}} = \sum_g q_{gm}^{\frac{\theta-1}{\theta}}$, and $s_{fm} = \frac{p_{fm} q_{fm}}{p_m q_m} = (\frac{p_{fm}}{p_m})^{1-\theta} = (\frac{q_{fm}}{q_m})^{\frac{\theta-1}{\theta}}$.

Now, it suffices to show that $\varepsilon_m^{-1} = \eta(1 - s_m) + s_m$. Totally differentiating the inverse demand for the material composite, obtained by inverting the outer-CES factor demand $M_m = (1 - a^D_{n,L})(\frac{P^M_m}{c^D_m})^{-\eta}\frac{Q^D_m}{A^D_m}$, we obtain that

$$d\ln P^M_m \;=\; -\frac{1}{\eta}\, d\ln M_m + \left(\frac{1}{\eta} - 1\right) d\ln Q^D_m. \tag{B.2}$$

The first term is the partial elasticity holding Q^D_m fixed and the second captures the response of Q^D_m to changes in M_m.

Under monopolistic competition with constant markup in the downstream sector, $c^D_m \frac{Q^D_m}{A^D_m} = \frac{\delta-1}{\delta} E_m$ holds. Totally differentiating $c^D_m \frac{Q^D_m}{A^D_m} = \frac{\delta-1}{\delta} E_m$ and using that refinery firms take E_m as given, we obtain $d\ln c^D_m + d\ln Q^D_m = 0$. Totally differentiating the unit-cost, $d\ln c^D_m = s^M_m\, d\ln P^M_m + (1 - s^M_m) d\ln W_m$ and $d\ln W_m = 0$. Combining the above two expressions, we obtain

$$d\ln Q^D_m = -\, s^M_m\, d\ln P^M_m. \tag{B.3}$$

Substituting equation (B.3) into equation (B.2),

$$d\ln M_m = -(\eta(1 - s^M_m) + s^M_m) d\ln P^M_m. \tag{B.4}$$

Log-differentiating $q_m = a^q(\frac{p_m}{P^M_m})^{-\nu} M_m$,

$$d\ln q_m = -\nu\left(d\ln p_m - d\ln P^M_m\right) + d\ln M_m. \tag{B.5}$$

Totally differentiating price index of the material composite P^M_m,

$$d\ln P^M_m \;=\; s^q_m\, d\ln p_m, \tag{B.6}$$

where the equality comes from $d\ln P^D_m = 0$. Substituting equations (B.4) and (B.6) into equation (B.5), $d\ln q_m = -[\nu(1 - s^q_m) + \bar{\epsilon}_m s^q_m] d\ln p_m$, which rearranges to

$$-\frac{\partial \ln p_m}{\partial \ln q_m} \;=\; \varepsilon^{-1}_m = \frac{1}{\nu\,(1 - s^q_m) + s^q_m(\eta(1 - s^M_m) + s^M_m)}.$$

B.2 Derivation of χ_{fm}^{-1} in Equation (3.15)

For a rival firm $g \neq f$, the inverse demand is $p_{gm} = (\frac{q_{gm}}{q_m})^{-\frac{1}{\theta}} p_m$. Differentiating with respect to $\ln q_{fm}$, holding q_{gm} fixed,

$$\frac{\partial \ln p_{(-f)m}}{\partial \ln q_{fm}} = \frac{1}{\theta}\frac{\partial \ln q_m}{\partial \ln q_{fm}} + \frac{\partial \ln p_m}{\partial \ln q_m}\frac{\partial \ln q_m}{\partial \ln q_{fm}} = -s_{fm}\left(\frac{1}{\varepsilon_m} - \frac{1}{\theta}\right) = \epsilon_{fm}^{-1} - \theta^{-1},$$

where the last inequality comes from $\epsilon_{fm}^{-1} - \theta^{-1} = \theta^{-1}(1 - s_{fm}) + \frac{s_{fm}}{\varepsilon_m} - \theta^{-1} = s_{fm}(\frac{1}{\varepsilon_m} - \frac{1}{\theta})$.

B.3 Derivation of ζ_{fm}^{-1} in Equation (3.16)

ζ_{fm}^{-1} is the sensitivity of ϵ_{fm}^{-1} to the composite refinery price, holding market shares s_{fm} fixed:

$$\zeta_{fm}^{-1} \equiv -\frac{\partial \epsilon_{fm}^{-1}}{\partial \ln p_m} = -s_{fm}\frac{\partial \varepsilon_m^{-1}}{\partial \ln p_m} = \frac{s_{fm}}{\varepsilon_m}\frac{\partial \ln \varepsilon_m}{\partial \ln p_m} = \frac{s_{fm}}{\varepsilon_m}\Gamma_m.$$

Re-writing $\varepsilon_m = \nu + s_m^q(\eta(1 - s_m^M) + s_m^M - \nu)$,

$$\frac{\partial \varepsilon_m}{\partial \ln p_m} = \Big((\eta(1 - s_m^M) + s_m^M - \nu\Big)\frac{\partial s_m^q}{\partial \ln p_m} + s_m^q\frac{\partial(\eta(1 - s_m^M) + s_m^M - \nu)}{\partial \ln p_m}. \tag{B.7}$$

For the first term, log-differentiating $s_m^q = a^q\big(\frac{p_m}{P_m^M}\big)^{1-\nu}$ and using $d\ln P_m^M = s_m^q\, d\ln p_m$,

$$\frac{\partial \ln s_m^q}{\partial \ln p_m} = (1 - \nu)\big(1 - s_m^q\big).$$

This gives that the first term of the right hand side in equation (B.7) becomes

$$\Big((\eta(1 - s_m^M) + s_m^M - \nu\Big)(1 - \nu)s_m^q(1 - s_m^q)$$

For the second term, from $s_m^M = \frac{(1-a_{n,L}^D)(P_m^M)^{1-\eta}}{(1-a_{n,L}^D)(P_m^M)^{1-\eta} + a_{n,L}^D W_m^{1-\eta}}$ and $d\ln P_m^M = s_m^q\, d\ln p_m$, we obtain $d\ln s_m^M = -(\eta - 1)(1 - s_m^M)\, d\ln P_m^M = -(\eta - 1)(1 - s_m^M)\, s_m^q\, d\ln p_m$. From this expression, we obtain

$$\frac{\partial(\eta(1 - s_m^M) + s_m^M - \nu)}{\partial \ln p_m} = (\eta - 1)^2\, s_m^M(1 - s_m^M)\, s_m^q.$$

Combining the two terms gives (3.16):

$$\Gamma_m = \frac{(\varepsilon_m - \nu)(1-\nu)(1-s_m^q) + (\eta-1)^2 s_m^M(1-s_m^M)(s_m^q)^2}{\varepsilon_m}.$$

B.4 Proof of Proposition 1

Proof. Under unconstrained monopoly achieved by letting $F \to \infty$, the incumbent market share within the refinery nest equals 1 (i.e., $s_{im} = 1$). Thus, the total revenue from refinery composite equals the incumbent's revenue and $p_{im} = p_m$. Under the unconstrained monopoly, choosing p_m and q_m is equivalent as there is a one-to-one relationship. Let $R(p_m) \equiv p_m q_m(p_m)$ denote the monopolist's revenue, which can be expressed as:

$$R(p_m) = s_m^q(p_m) s_m^M(p_m) \frac{\delta-1}{\delta} E_m. \tag{B.8}$$

From Appendix B.1, the two shares move with the monopolist's price according to

$$\frac{\partial \ln s_m^q}{\partial \ln p_m} = (1-\nu)\big(1-s_m^q\big), \qquad \frac{\partial \ln s_m^M}{\partial \ln p_m} = -(\eta-1)\big(1-s_m^M\big)s_m^q \tag{B.9}$$

Note that $q_m(p_m)$ is finite and strictly positive at every $p_m > 0$ and strictly decreasing, since $-\frac{\partial \ln q_m}{\partial \ln p_m} = \varepsilon_m > 0$ (equation 3.14).

We show that if $\max(\nu, \eta) \leq 1$, no maximizer exists. By equation (B.9), $\nu \leq 1$ and $\eta \leq 1$ imply that both shares are nondecreasing in p_m, so $R(p_m)$ is nondecreasing. Then for any $p_2 > p_1 > 0$,

$$\pi(p_2) - \pi(p_1) \;=\; \big[R(p_2) - R(p_1)\big] > 0.$$

This implies that profit is therefore strictly increasing in prices and the markup becomes unbounded. This happens because with complements at both nests, restricting quantity weakly raises the incumbent's shares of fixed expenditures at both layers of the nest while strictly saving production cost, so further decreasing quantities produced is always profitable.

Because profit is continuous in p_m, equals zero at $p_m = 0$, and is strictly positive at every $p_m \in (0, \infty)$, it suffices to show $\pi(p_m) \to 0$ as $p_m \to \infty$. A continuous function that is positive in the interior of $(0, \infty)$ and goes to zero at both ends attains its maximum at an interior point $p_m^* \in (0, \infty)$. Since $\pi_{im} \leq R = s_m^q s_m^M \frac{\delta-1}{\delta} E_m$, it suffices that one of the two shares, s_m^q or s_m^M, in the revenue formula goes to zero in the limit.

If $\nu > 1$, $s_m^q = \frac{a^q p_m^{1-\nu}}{a^q p_m^{1-\nu} + (1-a^q)(P_m^D)^{1-\nu}} \to 0$ as $p_m \to \infty$, because the exponent $1-\nu$ is negative. Hence, $R \to 0$. If $\nu \leq 1 < \eta$, $P_m^M \to \infty$ as $p_m \to \infty$, since for $\nu < 1$, $P_m^M \geq (a^q)^{\frac{1}{1-\nu}} p_m$ and at

$\nu = 1$, $P_m^M \propto p_m^{a^q}$). Therefore, $s_m^M = \left[1 + \frac{a_{n,L}^D}{1-a_{n,L}^D}(P_m^M/W_m)^{\eta-1}\right]^{-1} \longrightarrow 0$. Hence $R \longrightarrow 0$.

Finally, at the interior maximum the first-order condition $p_m^*\left(1 - \varepsilon_m(p_m^*)^{-1}\right) = c_{im}$ requires $\varepsilon_m(p_m^*) > 1$, so the markup $\frac{p_m^*}{c_{im}} = \frac{\varepsilon_m(p_m^*)}{\varepsilon_m(p_m^*)-1}$ is finite. □

B.5 Proof of Proposition 2

In this section, we provide a more general version with a fringe firm. This version incorporates two scenarios: there exists a fringe firm in one country that exports to all countries; or there exists a fringe firm $\tilde{f}$ in each country, which cannot export and serves only its domestic country. The key difference between this fringe firm and the incumbent (or the entrant) is that the fringe firm charges monopolistically competitive constant markups and do not attain oligopolistic market power.

Proposition 2 can then be reformulated as the following proposition. The expression becomes more complicated because the incumbent takes fringe firms' quantity decisions into account when it makes quantity decisions. It is straightforward to check that without fringe firms, the variables with $\tilde{f}$ subscript are dropped out and Proposition B.1 collapses to Proposition 2.

Proposition B.1. *In the case of Stackelberg duopoly, the entrant charges*

$$p_{em} = \frac{\epsilon_{em}}{\epsilon_{em} - 1}\frac{c_{em}}{z_e}. \tag{B.10}$$

The incumbent charges

$$p_{im} = \frac{\epsilon_{im}}{\epsilon_{im} - 1 + \frac{\chi_{im}^{-1}}{\epsilon_{\tilde{f}m}^{-1}}\frac{\chi_{\tilde{f}m}^{-1}}{\epsilon_{im}^{-1}} + \frac{\hat{\chi}_{em}^{-1}}{\epsilon_{im}^{-1}}\left[-\frac{d\ln q_{em}^{BR}}{d\ln q_{im}}\right]}\frac{c_{im}}{z_i} \tag{B.11}$$

where

$$\frac{d\ln q_{em}^{BR}}{d\ln q_{im}} = -\frac{\hat{\chi}_{im}^{-1} + \frac{\theta-1}{\epsilon_{em}-1}\frac{\chi_{em}^{-1}}{\epsilon_{em}^{-1}}\left((1-s_{em})\hat{\chi}_{im}^{-1} - s_{im}\hat{\epsilon}_{im}^{-1}\right) + \frac{1}{\epsilon_{em}-1}\frac{\zeta_{em}^{-1}}{\epsilon_{em}^{-1}}(s_{im}\hat{\epsilon}_{im}^{-1} + s_{em}\hat{\chi}_{im}^{-1})}{\hat{\epsilon}_{em}^{-1} + \frac{\theta-1}{\epsilon_{em}-1}\frac{\chi_{em}^{-1}}{\epsilon_{em}^{-1}}\left((1-s_{em})\hat{\epsilon}_{em}^{-1} - s_{im}\hat{\chi}_{em}^{-1}\right) + \frac{1}{\epsilon_{em}-1}\frac{\zeta_{em}^{-1}}{\epsilon_{em}^{-1}}(s_{em}\hat{\epsilon}_{em}^{-1} + s_{im}\hat{\chi}_{em}^{-1})} \tag{B.12}$$

and, for $f \in \{i, e, \tilde{f}\}$,

$$\epsilon_{fm}^{-1} = \theta^{-1}(1 - s_{fm}) + \frac{s_{fm}}{\varepsilon_m}, \qquad \chi_{fm}^{-1} = \epsilon_{fm}^{-1} - \theta^{-1}, \qquad \varepsilon_m = \nu\,(1 - s_m^q) + s_m^q\left[\eta(1 - s_m^M) + s_m^M\right]$$

$$\zeta_{fm}^{-1} = \frac{s_{fm}}{\varepsilon_m}\Gamma_m, \quad \Gamma_m = \frac{\left(\eta(1-s_m^M)+s_m^M-\nu\right)(1-\nu)\, s_m^q(1-s_m^q)+(\eta-1)^2\, s_m^M(1-s_m^M)\,(s_m^q)^2}{\varepsilon_m}$$

$$\hat{\epsilon}_{fm}^{-1} = \epsilon_{fm}^{-1}\left(1-\frac{\chi_{\tilde{f}m}^{-1}}{\epsilon_{\tilde{f}m}^{-1}}\frac{\chi_{fm}^{-1}}{\epsilon_{fm}^{-1}}\right), \qquad \hat{\chi}_{fm}^{-1} = \left(1-\frac{\chi_{\tilde{f}m}^{-1}}{\epsilon_{\tilde{f}m}^{-1}}\right)\chi_{fm}^{-1}.$$

Proof. The proof proceeds in three steps. First, we show equation (B.10). Second, we show equation (B.11). Lastly, we show equation (B.12)

First, we show equation (B.10). The entrant's profit maximization problem is

$$\max_{\{q_{em}\}} \sum_{m\in\mathcal{N}} \pi_{em}(q_{im}, q_{em}, q_{\tilde{f}m}) \tag{B.13}$$

When choosing q_{em}, the entrant takes other firms' quantities, q_{im} and $q_{\tilde{f}m}$, as given. Its first-order condition is

$$\frac{\partial \pi_{em}}{\partial q_{em}} = \frac{\pi_{em}}{q_{em}}\left(\frac{\partial \ln\left(p_{em}-\frac{c_{em}}{z_e}\right)}{\partial \ln p_{em}}\frac{\partial \ln p_{em}}{\partial \ln q_{em}}+1\right) = \frac{\pi_{em}}{q_{em}}\left(\frac{p_{em}}{p_{em}-\frac{c_{em}}{z_e}}(-\epsilon_{em}^{-1})+1\right) = 0, \tag{B.14}$$

which gives

$$p_{em} = \frac{\epsilon_{em}}{\epsilon_{em}-1}\frac{c_{em}}{z_e}. \tag{B.15}$$

Second, we show equation (B.11). The incumbent's profit maximization problem is

$$\max_{\{q_{im}\}} \sum_{m\in\mathcal{N}} \pi_{im}(q_{im}, q_{em}, q_{\tilde{f}m}), \tag{B.16}$$

Unlike the fringe firm and the entrant, the incumbent takes other firms' quantity decisions into account. Its first-order condition is

$$\frac{\partial \pi_{im}}{\partial q_{im}} + \frac{\partial \pi_{im}}{\partial q_{em}}\frac{dq_{em}}{dq_{im}} + \frac{\partial \pi_{im}}{\partial q_{\tilde{f}m}}\frac{dq_{\tilde{f}m}}{dq_{im}} = 0,$$

which can be reformulated as

$$
\begin{aligned}
&1+\frac{\partial \ln\left(p_{im}-\frac{c_{im}}{z_i}\right)}{\partial \ln p_{im}}\left(\frac{\partial \ln p_{im}}{\partial \ln q_{im}}+\frac{\partial \ln p_{im}}{\partial \ln q_{em}}\frac{d\ln q_{em}}{d\ln q_{im}}+\frac{\partial \ln p_{im}}{\partial \ln q_{\tilde f m}}\frac{d\ln q_{\tilde f m}}{d\ln q_{im}}\right)=0\\
&\Leftrightarrow \frac{p_{im}}{p_{im}-\frac{c_{im}}{z_i}}\left(-\epsilon_{im}^{-1}+\chi_{em}^{-1}\left[-\frac{d\ln q_{em}}{d\ln q_{im}}\right]+\chi_{\tilde f m}^{-1}\left[-\frac{d\ln q_{\tilde f m}}{d\ln q_{im}}\right]\right)+1=0\\
&\Leftrightarrow p_{im}\left(-1+\frac{\chi_{em}^{-1}}{\epsilon_{im}^{-1}}\left[-\frac{d\ln q_{em}}{d\ln q_{im}}\right]+\frac{\chi_{\tilde f m}^{-1}}{\epsilon_{im}^{-1}}\left[-\frac{d\ln q_{\tilde f m}}{d\ln q_{im}}\right]\right)+\epsilon_{im}p_{im}=\epsilon_{im}\frac{c_{im}}{z_i}\\
&\Leftrightarrow p_{im}=\frac{\epsilon_{im}}{\epsilon_{im}-1+\frac{\chi_{em}^{-1}}{\epsilon_{im}^{-1}}\left[-\frac{d\ln q_{em}}{d\ln q_{im}}\right]+\frac{\chi_{\tilde f m}^{-1}}{\epsilon_{im}^{-1}}\left[-\frac{d\ln q_{\tilde f m}}{d\ln q_{im}}\right]}\frac{c_{im}}{z_i}
\end{aligned}
\tag{B.17}
$$

Next, we express $-\frac{d\ln q_{\tilde f m}}{d\ln q_{im}}$ in terms of $-\frac{d\ln q_{em}}{d\ln q_{im}}$. Using the fringe firm's inverse demand $p_{\tilde f m}=(\frac{q_{\tilde f m}}{q_m})^{-\frac{1}{\theta}}p_m$, the refinery composite-price elasticity $-\frac{\partial \ln p_m}{\partial \ln q_m}=\varepsilon_m^{-1}$ (derived in Appendix B.1), and $d\ln p_{\tilde f m}=0$ (as fringe firms always charge constant markups $p_{\tilde f m}=\frac{\theta}{\theta-1}\frac{c_{\tilde f m}}{z_{\tilde f}}$), we obtain

$$
\begin{aligned}
0&=-\theta^{-1}d\ln q_{\tilde f m}+\theta^{-1}d\ln q_m-\varepsilon_m^{-1}d\ln q_m\\
&=-\theta^{-1}d\ln q_{\tilde f m}+\left(\theta^{-1}-\varepsilon_m^{-1}\right)(s_{im}d\ln q_{im}+s_{em}d\ln q_{em}+s_{\tilde f m}d\ln q_{\tilde f m}).
\end{aligned}
$$

Using $s_{fm}(\theta^{-1}-\varepsilon_m^{-1})=-\chi_{fm}^{-1}$ and $-\theta^{-1}+s_{\tilde f m}(\theta^{-1}-\varepsilon_m^{-1})=-\epsilon_{\tilde f m}^{-1}$, the above expression can be re-expressed as follows:

$$
d\ln q_{\tilde f m}=-\frac{\chi_{im}^{-1}}{\epsilon_{\tilde f m}^{-1}}d\ln q_{im}-\frac{\chi_{em}^{-1}}{\epsilon_{\tilde f m}^{-1}}d\ln q_{em}. \tag{B.18}
$$

From the above expression (equation B.18), we obtain

$$
\frac{d\ln q_{\tilde f m}}{d\ln q_{im}}=-\frac{\chi_{im}^{-1}}{\epsilon_{\tilde f m}^{-1}}-\frac{\chi_{em}^{-1}}{\epsilon_{\tilde f m}^{-1}}\frac{d\ln q_{em}}{d\ln q_{im}}. \tag{B.19}
$$

Substituting equation (B.19) into the last line of equation (B.17), we obtain equation (B.11).

Lastly, it remains to show equation (B.12). We proceed by totally differentiating the best response of the entrant (equation B.10). Totally differentiating,

$$
d\ln p_{em}=\frac{1}{\epsilon_{em}-1}\frac{d\epsilon_{em}^{-1}}{\epsilon_{em}^{-1}}=\frac{1}{\epsilon_{em}-1}\left(\frac{\chi_{em}^{-1}}{\epsilon_{em}^{-1}}d\ln s_{em}-\frac{\zeta_{em}^{-1}}{\epsilon_{em}^{-1}}d\ln p_m\right), \tag{B.20}
$$

where the second equality uses $d\epsilon_{em}^{-1} = \chi_{em}^{-1}\, d\ln s_{em} + s_{em}\, d\varepsilon_m^{-1}$ (since $\chi_{em}^{-1} = s_{em}(\varepsilon_m^{-1} - \theta^{-1})$) together with $s_{em}\, d\varepsilon_m^{-1} = -\zeta_{em}^{-1}\, d\ln p_m$ from equation (3.16).

Also, totally differentiating the entrant's inverse demand $p_{em} = (\frac{q_{em}}{q_m})^{-\frac{1}{\theta}} p_m$ and using $\frac{\partial \ln p_m}{\partial \ln q_m} = -\varepsilon_m^{-1}$,

$$\begin{aligned} d\ln p_{em} &= -\theta^{-1} d\ln q_{em} + (\theta^{-1} - \varepsilon_m^{-1}) d\ln q_m \\ &= -\theta^{-1} d\ln q_{em} + (\theta^{-1} - \varepsilon_m^{-1})(s_{im} d\ln q_{im} + s_{em} d\ln q_{em} + s_{\tilde{f}m} d\ln q_{\tilde{f}m}) \\ &= -\epsilon_{em}^{-1} d\ln q_{em} - \chi_{im}^{-1} d\ln q_{im} - \chi_{\tilde{f}m}^{-1} d\ln q_{\tilde{f}m}. \end{aligned}$$

Substituting equation (B.18) into the above equation, we obtain that

$$d\ln p_{em} = -\hat{\epsilon}_{em}^{-1} d\ln q_{em} - \hat{\chi}_{im}^{-1} d\ln q_{im}. \tag{B.21}$$

Next, we calculate $d\ln s_{em}$ and $d\ln p_m$. Using that $s_{em} = \frac{p_{em}^{1-\theta}}{\sum_{f'} p_{f'm}^{1-\theta}}$ and $d\ln p_{\tilde{f}m} = 0$, we obtain

$$\begin{aligned} d\ln s_{em} &= -(\theta-1)(1-s_{em}) d\ln p_{em} + (\theta-1)s_{im} d\ln p_{im} + (\theta-1)s_{\tilde{f}m} d\ln p_{\tilde{f}m} \\ &= -(\theta-1)(1-s_{em}) d\ln p_{em} + (\theta-1)s_{im} d\ln p_{im} \end{aligned}$$

Substituting equation (B.21) and $d\ln p_{im} = -\hat{\epsilon}_{im}^{-1} d\ln q_{im} - \hat{\chi}_{em}^{-1} d\ln q_{em}$ (which can be derived similarly with equation (B.21)) into the above equation, we obtain

$$d\ln s_{em} = (\theta-1)[(1-s_{em})\hat{\epsilon}_{em}^{-1} - s_{im}\hat{\chi}_{em}^{-1}] d\ln q_{em} + (\theta-1)[(1-s_{em})\hat{\chi}_{im}^{-1} - s_{im}\hat{\epsilon}_{im}^{-1}] d\ln q_{im}. \tag{B.22}$$

Next, we express $d\ln p_m$ in terms of quantities. Using $d\ln p_m = s_{im}\, d\ln p_{im} + s_{em}\, d\ln p_{em}$ (with $d\ln p_{\tilde{f}m} = 0$) and substituting equation (B.21) together with $d\ln p_{im} = -\hat{\epsilon}_{im}^{-1} d\ln q_{im} - \hat{\chi}_{em}^{-1} d\ln q_{em}$,

$$-\, d\ln p_m = (s_{im}\hat{\epsilon}_{im}^{-1} + s_{em}\hat{\chi}_{im}^{-1})\, d\ln q_{im} + (s_{em}\hat{\epsilon}_{em}^{-1} + s_{im}\hat{\chi}_{em}^{-1})\, d\ln q_{em}. \tag{B.23}$$

It remains to combine equations (B.21), (B.22), (B.23), and (B.20) to obtain equation (B.12). Equating the two expressions for $d\ln p_{em}$, the one from totally differentiating the entrant's CES inverse demand (B.21) and the one from totally differentiating the entrant's markup (B.20), gives

$$-\hat{\epsilon}_{em}^{-1}\, d\ln q_{em} - \hat{\chi}_{im}^{-1}\, d\ln q_{im} = \frac{1}{\epsilon_{em}-1}\left(\frac{\chi_{em}^{-1}}{\epsilon_{em}^{-1}}\, d\ln s_{em} - \frac{\zeta_{em}^{-1}}{\epsilon_{em}^{-1}}\, d\ln p_m\right). \tag{B.24}$$

Substituting equation (B.22) for $d\ln s_{em}$ and equation (B.23) for $-d\ln p_m$ into the right-hand side (RHS), the RHS becomes a linear combination of $d\ln q_{em}$ and $d\ln q_{im}$:

$$\begin{aligned}\text{RHS} \;=& \left\{\frac{\theta-1}{\epsilon_{em}-1}\frac{\chi_{em}^{-1}}{\epsilon_{em}^{-1}}\left[(1-s_{em})\hat{\epsilon}_{em}^{-1}-s_{im}\hat{\chi}_{em}^{-1}\right]+\frac{1}{\epsilon_{em}-1}\frac{\zeta_{em}^{-1}}{\epsilon_{em}^{-1}}\left(s_{em}\hat{\epsilon}_{em}^{-1}+s_{im}\hat{\chi}_{em}^{-1}\right)\right\}d\ln q_{em}\\ &+\left\{\frac{\theta-1}{\epsilon_{em}-1}\frac{\chi_{em}^{-1}}{\epsilon_{em}^{-1}}\left[(1-s_{em})\hat{\chi}_{im}^{-1}-s_{im}\hat{\epsilon}_{im}^{-1}\right]+\frac{1}{\epsilon_{em}-1}\frac{\zeta_{em}^{-1}}{\epsilon_{em}^{-1}}\left(s_{im}\hat{\epsilon}_{im}^{-1}+s_{em}\hat{\chi}_{im}^{-1}\right)\right\}d\ln q_{im}.\end{aligned}$$

Equating this RHS with the LHS of equation (B.24) and collecting coefficients of $d\ln q_{em}$ and $d\ln q_{im}$,

$$\begin{aligned}&\underbrace{\left\{\hat{\epsilon}_{em}^{-1}+\frac{\theta-1}{\epsilon_{em}-1}\frac{\chi_{em}^{-1}}{\epsilon_{em}^{-1}}\left[(1-s_{em})\hat{\epsilon}_{em}^{-1}-s_{im}\hat{\chi}_{em}^{-1}\right]+\frac{1}{\epsilon_{em}-1}\frac{\zeta_{em}^{-1}}{\epsilon_{em}^{-1}}\left(s_{em}\hat{\epsilon}_{em}^{-1}+s_{im}\hat{\chi}_{em}^{-1}\right)\right\}}_{\equiv D}d\ln q_{em}\\ &+\underbrace{\left\{\hat{\chi}_{im}^{-1}+\frac{\theta-1}{\epsilon_{em}-1}\frac{\chi_{em}^{-1}}{\epsilon_{em}^{-1}}\left[(1-s_{em})\hat{\chi}_{im}^{-1}-s_{im}\hat{\epsilon}_{im}^{-1}\right]+\frac{1}{\epsilon_{em}-1}\frac{\zeta_{em}^{-1}}{\epsilon_{em}^{-1}}\left(s_{im}\hat{\epsilon}_{im}^{-1}+s_{em}\hat{\chi}_{im}^{-1}\right)\right\}}_{\equiv N}d\ln q_{im} \;=\; 0.\end{aligned}$$

Dividing by $D\,d\ln q_{im}$ and identifying $\frac{d\ln q_{em}}{d\ln q_{im}}$ along the entrant's best-response locus as $\frac{d\ln q_{em}^{BR}}{d\ln q_{im}}$,

$$\frac{d\ln q_{em}^{BR}}{d\ln q_{im}}=-\frac{N}{D},$$

which gives equation (B.12).

□

B.6 Proof of Proposition 3

In this section, similar to Proposition B.1, we provide a generalized version of Proposition 3 that incorporates fringe firms, stated as Proposition B.2 below. In the absence of fringe firms, the variables with subscript $\tilde{f}$ drop out and Proposition B.2 reduces to Proposition 3.

Proposition B.2. *(i) In the blockaded entry case, the incumbent charges*

$$p_{im}=\frac{\epsilon_{im}\left(1+\Psi\frac{\dot{\pi}_{em}}{\pi_{im}}\frac{\dot{\mu}_{em}}{\dot{\mu}_{em}-1}\left(\dot{\hat{\chi}}_{im}^{-1}+\dot{\chi}_{em}^{-1}\frac{\dot{\chi}_{\tilde{f}m}^{-1}}{\dot{\epsilon}_{\tilde{f}m}^{-1}}\left(-\frac{d\ln\dot{q}_{em}^{BR}}{d\ln\dot{q}_{im}}\right)\right)\right)}{\epsilon_{im}\left(1+\Psi\frac{\dot{\pi}_{em}}{\pi_{im}}\frac{\dot{\mu}_{em}}{\dot{\mu}_{em}-1}\left(\dot{\hat{\chi}}_{im}^{-1}+\dot{\chi}_{em}^{-1}\frac{\dot{\chi}_{\tilde{f}m}^{-1}}{\dot{\epsilon}_{\tilde{f}m}^{-1}}\left(-\frac{d\ln\dot{q}_{em}^{BR}}{d\ln\dot{q}_{im}}\right)\right)\right)-1+\frac{\chi_{\tilde{f}m}^{-1}}{\epsilon_{\tilde{f}m}^{-1}}\frac{\chi_{im}^{-1}}{\epsilon_{im}^{-1}}}\frac{c_{im}}{z_i},\qquad\text{(B.25)}$$

where a dot above a variable ($\dot{x}$) denotes its off-equilibrium value, evaluated in the subgame in which *the entrant enters and plays its best response, and* $\frac{d\ln \dot{q}_{em}^{BR}}{d\ln \dot{q}_{im}}$ *is defined analogously to equation* (B.12), *but evaluated at the off-the-equilibrium, with* $\hat{\chi}_{fm}$ *and* $\hat{\epsilon}_{fm}$ *defined in Proposition* B.1;

(ii) There exists a threshold $\bar{F}$ *such that whenever* $F \geq \bar{F}$, *the deterrence constraint does not bind* ($\Psi = 0$), *the incumbent charges its unconstrained markups over its unit costs* $p_{im} = \frac{\hat{\epsilon}_{im}}{\hat{\epsilon}_{im}-1}\frac{c_{im}}{z_i}$ *and the entrant does not enter;*

(iii) Conversely, as F falls, deterrence requires ever larger quantities, with markups approaching the perfectly competitive level, and the incumbent's profit under deterrence declines. There exists a threshold $\underline{F} < \bar{F}$ *such that for* $F \leq \underline{F}$, *the profit under deterrence falls below the Stackelberg duopoly profit and the incumbent accommodates entry rather than deterring it.*

Proof. Part (i) The incumbent's profit maximization problem can be formulated into the following Lagrangian:

$$\mathcal{L} = \max_{\{q_{im}\}} \sum_m \pi_{im}(q_{im}, q_{\tilde{f}m}) + \Psi\Big\{W_{n(e)}F - \sum_m \pi_{em}(q_{im}, q_{em}^{BR}, q_{\tilde{f}m})\Big\}, \tag{B.26}$$

where q_{em}^{BR} is the best response of the entrant given the quantity chosen by the incumbent:

$$q_{em}^{BR} = q_{em}^{BR}(q_{im}, q_{\tilde{f}m}) = \underset{q_{em}}{\operatorname{argmax}} \Big\{\pi_{em}(q_{im}, q_{em}, q_{\tilde{f}m})\Big\} \tag{B.27}$$

Due to the envelope theorem, the first-order condition can be expressed as:

$$\frac{\partial \pi_{im}}{\partial q_{im}} + \frac{\partial \pi_{im}}{\partial q_{\tilde{f}m}}\frac{dq_{\tilde{f}m}}{dq_{im}} - \Psi\left(\frac{\partial \dot{\pi}_{em}}{\partial q_{im}} + \frac{\partial \dot{\pi}_{em}}{\partial \dot{q}_{\tilde{f}m}}\frac{d\dot{q}_{\tilde{f}m}}{dq_{im}}\right) = 0.$$

The above expression can be written in terms of log derivatives:

$$\left(\frac{\partial \ln \pi_{im}}{\partial \ln q_{im}} + \frac{\partial \ln \pi_{im}}{\partial \ln q_{\tilde{f}m}}\frac{d\ln q_{\tilde{f}m}}{d\ln q_{im}}\right) - \Psi\frac{\dot{\pi}_{em}}{\pi_{im}}\left(\frac{\partial \ln \dot{\pi}_{em}}{\partial \ln q_{im}} + \frac{\partial \ln \dot{\pi}_{em}}{\partial \ln \dot{q}_{\tilde{f}m}}\frac{d\ln \dot{q}_{\tilde{f}m}}{d\ln q_{im}}\right) = 0. \tag{B.28}$$

We expand the two brackets in turn.

Since entry is deterred, the entrant does not operate and the incumbent's realized profit is $\pi_{im} = (p_{im} - \frac{c_{im}}{z_i})\,q_{im}$, so $\ln \pi_{im} = \ln\left(p_{im} - \frac{c_{im}}{z_i}\right) + \ln q_{im}$. Using $\frac{\partial \ln(p_{im} - c_{im}/z_i)}{\partial \ln p_{im}} = \frac{p_{im}}{p_{im} - c_{im}/z_i}$, the own-price elasticity $\frac{\partial \ln p_{im}}{\partial \ln q_{im}} = -\epsilon_{im}^{-1}$, the cross-elasticity $\frac{\partial \ln p_{im}}{\partial \ln q_{\tilde{f}m}} = -\chi_{\tilde{f}m}^{-1}$, and the fringe's response to the incumbent $\frac{d \ln q_{\tilde{f}m}}{d \ln q_{im}} = -\frac{\chi_{im}^{-1}}{\epsilon_{\tilde{f}m}^{-1}}$ (equation (B.18) with the entrant absent),

$$\frac{\partial \ln \pi_{im}}{\partial \ln q_{im}} + \frac{\partial \ln \pi_{im}}{\partial \ln q_{\tilde{f}m}} \frac{d \ln q_{\tilde{f}m}}{d \ln q_{im}} = \frac{p_{im}}{p_{im} - \frac{c_{im}}{z_i}} \left(-\epsilon_{im}^{-1} + \chi_{im}^{-1} \frac{\chi_{\tilde{f}m}^{-1}}{\epsilon_{\tilde{f}m}^{-1}} \right) + 1.$$

The entrant's off-equilibrium quantity is its own best response, $\dot{q}_{em} = \dot{q}_{em}^{BR}$, so $\frac{\partial \dot{\pi}_{em}}{\partial \dot{q}_{em}} = 0$. Hence q_{im} moves $\dot{\pi}_{em}$ only through the entrant's price, via the incumbent's and the fringe's quantities, not through $\dot{q}_{em}$. Using $\frac{\dot{p}_{em}}{\dot{p}_{em} - \dot{c}_{em}/z_e} = \frac{\dot{\mu}_{em}}{\dot{\mu}_{em} - 1}$ (since $\dot{p}_{em} = \dot{\mu}_{em} \frac{\dot{c}_{em}}{z_e}$), $\frac{\partial \ln \dot{p}_{em}}{\partial \ln q_{im}} = -\dot{\chi}_{im}^{-1}$, and $\frac{\partial \ln \dot{p}_{em}}{\partial \ln \dot{q}_{\tilde{f}m}} = -\dot{\chi}_{\tilde{f}m}^{-1}$,

$$\begin{aligned} \frac{\partial \ln \dot{\pi}_{em}}{\partial \ln q_{im}} + \frac{\partial \ln \dot{\pi}_{em}}{\partial \ln \dot{q}_{\tilde{f}m}} \frac{d \ln \dot{q}_{\tilde{f}m}}{d \ln q_{im}} &= \frac{\dot{p}_{em}}{\dot{p}_{em} - \frac{\dot{c}_{em}}{z_e}} \left(\frac{\partial \ln \dot{p}_{em}}{\partial \ln q_{im}} + \frac{\partial \ln \dot{p}_{em}}{\partial \ln \dot{q}_{\tilde{f}m}} \frac{d \ln \dot{q}_{\tilde{f}m}}{d \ln q_{im}} \right) \\ &= \frac{\dot{\mu}_{em}}{\dot{\mu}_{em} - 1} \left(-\dot{\chi}_{im}^{-1} - \dot{\chi}_{\tilde{f}m}^{-1} \frac{d \ln \dot{q}_{\tilde{f}m}}{d \ln q_{im}} \right). \end{aligned} \tag{B.29}$$

Unlike the incumbent bracket, here the fringe response $\frac{d \ln \dot{q}_{\tilde{f}m}}{d \ln q_{im}}$ is with dots, since at the off-equilibrium it depends on the entrant's best response.

Substituting both expansions in equation (B.28) into the log-derivative first-order condition gives

$$\frac{p_{im}}{p_{im} - \frac{c_{im}}{z_i}} \left(-\epsilon_{im}^{-1} + \chi_{im}^{-1} \frac{\chi_{\tilde{f}m}^{-1}}{\epsilon_{\tilde{f}m}^{-1}} \right) + 1 - \Psi \frac{\dot{\pi}_{em}}{\pi_{im}} \frac{\dot{\mu}_{em}}{\dot{\mu}_{em} - 1} \left(-\dot{\chi}_{im}^{-1} - \dot{\chi}_{\tilde{f}m}^{-1} \frac{d \ln \dot{q}_{\tilde{f}m}}{d \ln q_{im}} \right) = 0. \tag{B.30}$$

Following the same logic as in the derivation of equation (B.18) but at the off-equilibrium, we totally differentiate the fringe firm's inverse demand $\dot{p}_{\tilde{f}m} = \left(\frac{\dot{q}_{\tilde{f}m}}{\dot{q}_m} \right)^{-\frac{1}{\theta}} \dot{p}_m$ using the off-equilibrium composite-price elasticity $\frac{\partial \ln \dot{p}_m}{\partial \ln \dot{q}_m} = -\dot{\epsilon}_m^{-1}$ and the constant fringe markup $\dot{p}_{\tilde{f}m} = \frac{\theta}{\theta - 1} \frac{c_{\tilde{f}m}}{z_{\tilde{f}}}$ (so $d \ln \dot{p}_{\tilde{f}m} = 0$):

$$d \ln \dot{q}_{\tilde{f}m} = -\frac{\dot{\chi}_{im}^{-1}}{\dot{\epsilon}_{\tilde{f}m}^{-1}} d \ln q_{im} - \frac{\dot{\chi}_{em}^{-1}}{\dot{\epsilon}_{\tilde{f}m}^{-1}} d \ln \dot{q}_{em},$$

which gives

$$\frac{d \ln \dot{q}_{\tilde{f}m}}{d \ln q_{im}} = -\frac{\dot{\chi}_{im}^{-1}}{\dot{\epsilon}_{\tilde{f}m}^{-1}} - \frac{\dot{\chi}_{em}^{-1}}{\dot{\epsilon}_{\tilde{f}m}^{-1}} \frac{d \ln \dot{q}_{em}}{d \ln q_{im}}, \tag{B.31}$$

where $\dot{\epsilon}_m = \nu\,(1-\dot{s}_m^q) + \dot{s}_m^q\left[\eta(1-\dot{s}_m^M) + \dot{s}_m^M\right]$ is the composite elasticity evaluated at the off-equilibrium cost shares, and the elasticity objects $\dot{\epsilon}_{\tilde{f}m}^{-1}, \dot{\chi}_{im}^{-1}, \dot{\chi}_{em}^{-1}$ are built from the definitions in Proposition B.1 but evaluated at the off-equilibrium.

We obtain equation (B.25) in three steps. First, substitute the off-equilibrium fringe response in equation (B.31) into the entrant bracket of equation (B.30):

$$-\dot{\chi}_{im}^{-1} - \dot{\chi}_{\tilde{f}m}^{-1}\frac{d\ln\dot{q}_{\tilde{f}m}}{d\ln q_{im}} = -\dot{\chi}_{im}^{-1}\left(1-\frac{\dot{\chi}_{\tilde{f}m}^{-1}}{\dot{\epsilon}_{\tilde{f}m}^{-1}}\right) + \dot{\chi}_{em}^{-1}\frac{\dot{\chi}_{\tilde{f}m}^{-1}}{\dot{\epsilon}_{\tilde{f}m}^{-1}}\frac{d\ln\dot{q}_{em}}{d\ln q_{im}} = -\dot{\hat{\chi}}_{im}^{-1} - \dot{\chi}_{em}^{-1}\frac{\dot{\chi}_{\tilde{f}m}^{-1}}{\dot{\epsilon}_{\tilde{f}m}^{-1}}\left(-\frac{d\ln\dot{q}_{em}}{d\ln q_{im}}\right),$$

where the first two terms collapse to $-\dot{\hat{\chi}}_{im}^{-1}$ by the definition $\dot{\hat{\chi}}_{im}^{-1} = (1-\dot{\chi}_{\tilde{f}m}^{-1}/\dot{\epsilon}_{\tilde{f}m}^{-1})\dot{\chi}_{im}^{-1}$. Second, this bracket enters equation (B.30) pre-multiplied by $-\Psi\frac{\dot{\pi}_{em}}{\pi_{im}}\frac{\dot{\mu}_{em}}{\dot{\mu}_{em}-1}$, which flips its overall sign. Collecting terms, equation (B.30) becomes

$$\frac{p_{im}}{p_{im}-\frac{c_{im}}{z_i}}\left(-\epsilon_{im}^{-1} + \chi_{im}^{-1}\frac{\chi_{\tilde{f}m}^{-1}}{\epsilon_{\tilde{f}m}^{-1}}\right) + 1 + \Phi = 0, \quad \Phi \equiv \Psi\frac{\dot{\pi}_{em}}{\pi_{im}}\frac{\dot{\mu}_{em}}{\dot{\mu}_{em}-1}\left(\dot{\hat{\chi}}_{im}^{-1} + \dot{\chi}_{em}^{-1}\frac{\dot{\chi}_{\tilde{f}m}^{-1}}{\dot{\epsilon}_{\tilde{f}m}^{-1}}\left(-\frac{d\ln\dot{q}_{em}^{BR}}{d\ln q_{im}}\right)\right).$$

Third, solving for the markup factor, $\frac{p_{im}}{p_{im}-c_{im}/z_i} = \frac{1+\Phi}{\epsilon_{im}^{-1}-\chi_{im}^{-1}(\chi_{\tilde{f}m}^{-1}/\epsilon_{\tilde{f}m}^{-1})}$, using $p_{im} = \frac{M}{M-1}\frac{c_{im}}{z_i}$, and multiplying numerator and denominator by ϵ_{im} delivers equation (B.25).

<u>*Part (ii)*</u> Define

$$\bar{F} \equiv \frac{1}{W_{n(e)}}\sum_m \dot{\pi}_{em}\big(q_{im}^{mon}, \dot{q}_{em}^{BR}(q_{im}^{mon}), \dot{q}_{\tilde{f}m}\big), \tag{B.32}$$

the profit the entrant would earn if it entered and played its best response against $\{q_{im}^{mon}\}$.

Suppose $F \geq \bar{F}$, in which case the entrant's post-entry profit does not cover the fixed cost and the entrant stays out. Then, the constraint becomes slack, the constrained and unconstrained optima coincide, and complementary slackness gives $\Psi = 0$. Setting $\Psi = 0$ in equation (B.25) and using $\epsilon_{im}\hat{\epsilon}_{im}^{-1} = 1 - \frac{\chi_{\tilde{f}m}^{-1}}{\epsilon_{\tilde{f}m}^{-1}}\frac{\chi_{im}^{-1}}{\epsilon_{im}^{-1}}$, which follows from the definition of $\hat{\epsilon}_{fm}^{-1}$ in Proposition B.1, the denominator becomes $\epsilon_{im}\big(1-\hat{\epsilon}_{im}^{-1}\big)$, so that

$$p_{im} = \frac{\hat{\epsilon}_{im}}{\hat{\epsilon}_{im}-1}\frac{c_{im}}{z_i}, \tag{B.33}$$

the incumbent's unconstrained price against the fringe, with all objects evaluated at $s_{em} = 0$ so that $s_{im} + s_{\tilde{f}m} = 1$.

In the absence of the fringe firm, the incumbent becomes an unconstrained monopolist, $\tilde{f}$ terms drop out, $\hat{\epsilon}_{im} = \epsilon_{im}$, and equation (B.33) reduces to the unconstrained monopoly price of Proposition 3.

Part (iii) Let $D(F) \equiv \{\{q_{im}\} : \frac{1}{W_{n(e)}} \sum_m \dot{\pi}_{em} \leq F\}$ and let $\Pi^{de}(F) \equiv \sup_{\{q_{im}\} \in D(F)} \sum_m \pi_{im}$ denote the incumbent's value under deterrence. Sublevel sets are nested by construction, $D(F) \subseteq D(F')$ for $F \leq F'$, so Π^{de} is nondecreasing, and $\Pi^{de}(F) = \Pi^{mon}$ for $F \geq \bar{F}$ by part (ii). The accommodation value Π^{duo}, the incumbent's Stackelberg duopoly profit, is independent of F, since the fixed cost is paid by the entrant and enters no quantity first-order condition, and satisfies $\Pi^{duo} < \Pi^{mon}$ because goods are substitutes.

Next, over any bounded set of incumbent quantities, the entrant's off-path profit is bounded below by a strictly positive constant, because its residual price grows without bound as its own quantity vanishes, so an arbitrarily small sale earns a price strictly above marginal cost. Thus, to deter entry at small F, the incumbent must set very large quantities, $q_{im} \to \infty$. The revenue bound $p_{im} q_{im} \leq E_m$ from equation (B.8) then forces $p_{im} \to 0$ against a constant marginal cost, so the incumbent's markup under deterrence declines toward the competitive level and eventually below it, and $\pi_{im} \leq E_m - \frac{c_{im}}{z_i} q_{im} \to -\infty$. Hence there exists $F_0 > 0$ with $\Pi^{de}(F) < \Pi^{duo}$ for all $F \leq F_0$.

Define $\underline{F} \equiv \inf\{F > 0 : \Pi^{de}(F) \geq \Pi^{duo}\} \in [F_0, \bar{F}]$. Monotonicity delivers the threshold behavior, so the incumbent accommodates entry for $F < \underline{F}$ and deters for $F > \underline{F}$. Finally, $\underline{F} < \bar{F}$ strictly, because the entrant's off-path profit is locally decreasing in the incumbent's quantities at the monopoly configuration, so configurations feasible at F slightly below $\bar{F}$ exist arbitrarily close to the monopoly quantities and $\Pi^{de}(F) \to \Pi^{mon} > \Pi^{duo}$ as $F \uparrow \bar{F}$.

□

C. Appendix: Calibration

C.1 Computational Algorithm

In this section, we explain our computational algorithm for solving the model, calibration, and counterfactuals.

Calibration.

1. Given the set of externally calibrated parameters, assign initial guess values to $\{z_e, a_L^R, a^q, \bar{\varsigma}_{\text{US}}^R, z_{\tilde{f}}\}$. Also, assign initial values to downstream intermediate input intensity, $\{A_n^{0,(0)}, A_n^{D,(0)}, A_n^{U,(0)}, a_{n,L}^{D,(0)}\}$.
2. Given the initial guess, we solve the model through fixed-point iteration on $\{p_i, p_{\tilde{f}}, p_e, X_n, P_n^D\}$. We update the values using $x^{(t+1)} = (1-\lambda)x^{(t)} + \lambda f(x^{(t)})$ for $x \in \{p_i, p_e, p_{\tilde{f}},$

$P_n^D, X_n\}$, with a damping factor $\lambda \in (0,1)$. Iteration continues until the updates fall below the tolerance.

3. While solving the model, we update $\{A_n^0, A_n^D, A_n^U, a_{n,L}^D\}$ as follows:

   (a) Compute the following log residuals of each targeted distribution relative to the US:

   $$r_n^{GDP} = \ln\left(\frac{GDP_n}{GDP_{\text{US}}} \middle/ \frac{GDP_n^{\text{data}}}{GDP_{\text{US}}^{\text{data}}}\right),\ r_n^{VA} = \ln\left(\frac{VA_n}{VA_{\text{US}}} \middle/ \frac{VA_n^{\text{data}}}{VA_{\text{US}}^{\text{data}}}\right),\ r_n^{X} = \ln\left(\frac{X_n}{X_{\text{US}}} \middle/ \frac{X_n^{\text{data}}}{X_{\text{US}}^{\text{data}}}\right),$$

   where GDP_n is model nominal income, VA_n is downstream value added, and X_n is mining output. Based on these residuals, update the fundamentals as follows:

   $$A_n^{0,(1)} = A_n^{0,(0)} e^{-\kappa_n^0 r_n^{GDP}}, \qquad A_n^{D,(1)} = A_n^{D,(0)} e^{-\kappa_n^D r_n^{VA}}, \qquad A_n^{U,(1)} = A_n^{U,(0)} e^{-\kappa_n^U r_n^{X}}.$$

   The per-country step sizes κ_n adapt to the iteration history for stability.

   (b) The downstream labor weight is then pinned in closed form so that every country matches its target material share $s_n^{M,\text{data}}$. Inverting the CES cost share $s_n^M = \frac{(1-\mu_n)(P_n^M)^{1-\eta}}{\mu_n (A_n^{0,(1)})^{1-\eta} + (1-\mu_n)(P_n^M)^{1-\eta}}$ gives

   $$a_{n,L}^{D\prime} = \frac{(P_n^M)^{1-\eta}(1 - s_n^{M,\text{data}})}{(P_n^M)^{1-\eta}(1 - s_n^{M,\text{data}}) + s_n^{M,\text{data}} (A_n^{0,(1)})^{1-\eta}} \in (0,1). \tag{C.1}$$

   Then, we obtain the updated guess as a geometric average, $a_{n,L}^{D,(1)} = 1-(1-a_{n,L}^{D,(0)})^{1-\lambda_\mu}(1-a_{n,L}^{D\prime})^{\lambda_\mu}$, with a damping factor $\lambda_\mu \in (0,1)$.

   (c) The loop continues until the largest absolute log residual of each distribution and the largest deviation of the material shares from their targets fall below tolerance.

4. After solving the model with the updated fundamentals, we compute the five moments. The five parameters are updated by nonlinear least squares on the five moment residuals. Because the system is exactly identified, the procedure is equivalent to finding a root of the system of five moment equations.

5. Given the converged calibration, we solve the accommodated duopoly at the calibrated subsidy and set F equal to the entrant's operating profit relative to the US wage, the break-even level.

Counterfactuals. When solving counterfactuals with entry deterrence, we need to solve for Ψ, which satisfies a complementary-slackness condition. If the entrant's off-path profit at the incumbent's unconstrained conduct is below the entry cost, then $\Psi = 0$ and the incumbent charges an unconstrained markup. Otherwise the incumbent expands supply until the entrant's off-path profit exactly equals the entry cost.

C.2 Additional Figures and Tables

Table C.1: Gravity Estimation Results

	rare earth (Mining & refinery combined)		Downstream	
	Step 1	Step 2	Step 1	Step 2
Dep. Var.	Trade Values	Recovered Bilateral FE	Trade Values	Recovered Bilateral FE
	(1)	(2)	(3)	(4)
Log tariff	−3.226		-0.639^{**}	
	(2.374)		(0.287)	
FTA (WTO)		-0.590^{**}		0.567^{*}
		(0.267)		(0.287)
Log distance		−0.174		-0.508^{***}
		(0.132)		(0.130)
Common language		0.546^{*}		1.370^{***}
		(0.319)		(0.390)
Common colony		−0.363		-1.192^{***}
		(0.510)		(0.450)
Origin-year FE	✓		✓	
Dest-year FE	✓		✓	
Bilateral FE	✓		✓	
Obs.	13,079	13,079	80,375	80,375

Notes. This table reports gravity estimation results. Column 1 reports the PPML estimates of equation (4.1) for the combined rare earth mining and refining sector. Column 2 regresses the bilateral fixed effects backed out from column 1 on an FTA dummy, log distance, a common-language dummy, and a common-colony dummy. Columns 3–4 report the same estimations for the downstream sector.

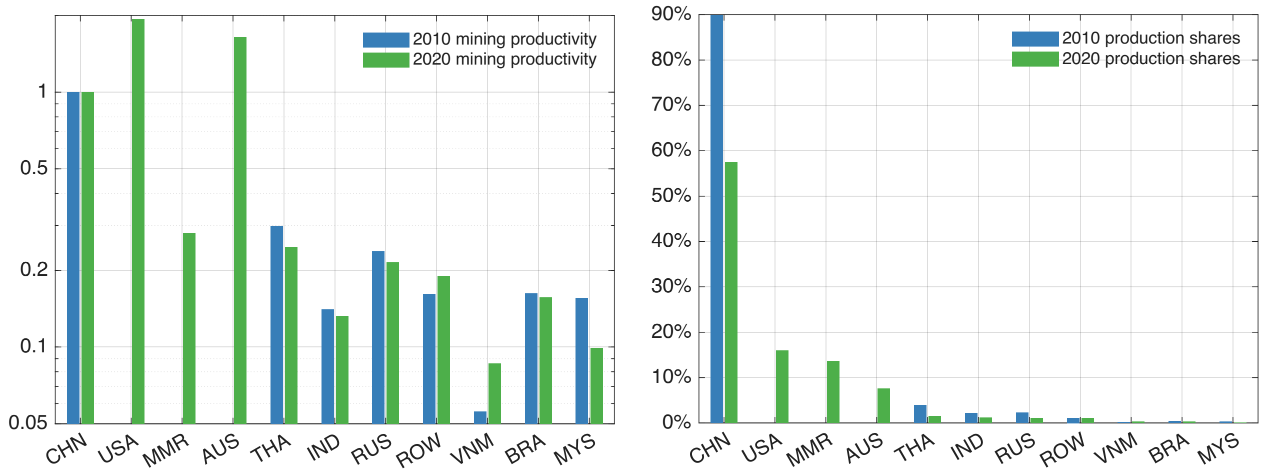
Table C.2: Countries and Mining / Refinery Production

	Mining		Refining		Mining		Refining
Country	2010	2022		Country	2010	2022	
Angola (AGO)				Kazakhstan (KAZ)			
Argentina (ARG)				Latvia (LVA)			
Australia (AUS)		✓		Lithuania (LTU)			
Austria (AUT)				Luxembourg (LUX)			
Bangladesh (BGD)				Malaysia (MYS)	✓	✓	✓(robustness)
Belarus (BLR)				Malta (MLT)			
Belgium (BEL)				Mexico (MEX)			
Brazil (BRA)	✓	✓		Morocco (MAR)			
Bulgaria (BGR)				Myanmar (MMR)		✓	
Canada (CAN)				Netherlands (NLD)			
Chile (CHL)				Nigeria (NGA)			
China (CHN)	✓	✓	✓(incumbent)	Norway (NOR)			
Colombia (COL)				Poland (POL)			
Costa Rica (CRI)				Portugal (PRT)			
Cote d'Ivoire (CIV)				Romania (ROU)			
Croatia (HRV)				Russia (RUS)	✓	✓	
Cyprus (CYP)				Sao Tome and Principe (STP)			
Czechia (CZE)				Saudi Arabia (SAU)			
DR Congo (COD)				Singapore (SGP)			
Denmark (DNK)				Slovakia (SVK)			
Egypt (EGY)				Slovenia (SVN)			
Estonia (EST)				South Africa (ZAF)			
Finland (FIN)				South Korea (KOR)			
France (FRA)				Spain (ESP)			
Germany (DEU)				Sweden (SWE)			
Greece (GRC)				Switzerland (CHE)			
Hong Kong (HKG)				Thailand (THA)	✓	✓	
Hungary (HUN)				Tunisia (TUN)			
Iceland (ISL)				Turkiye (TUR)			
India (IND)	✓	✓		Ukraine (UKR)			
Indonesia (IDN)				United Arab Emirates (ARE)			
Ireland (IRL)				United Kingdom (GBR)			
Israel (ISR)				United States (USA)		✓	✓(entrant)
Italy (ITA)				Vietnam (VNM)	✓	✓	
Japan (JPN)				Rest of the World (Others)		✓	
Jordan (JOR)							

Notes. This table reports the set of countries used in the quantitative exercises and their production in the rare earth mining and refining industries.

D. Appendix: Quantitative Results

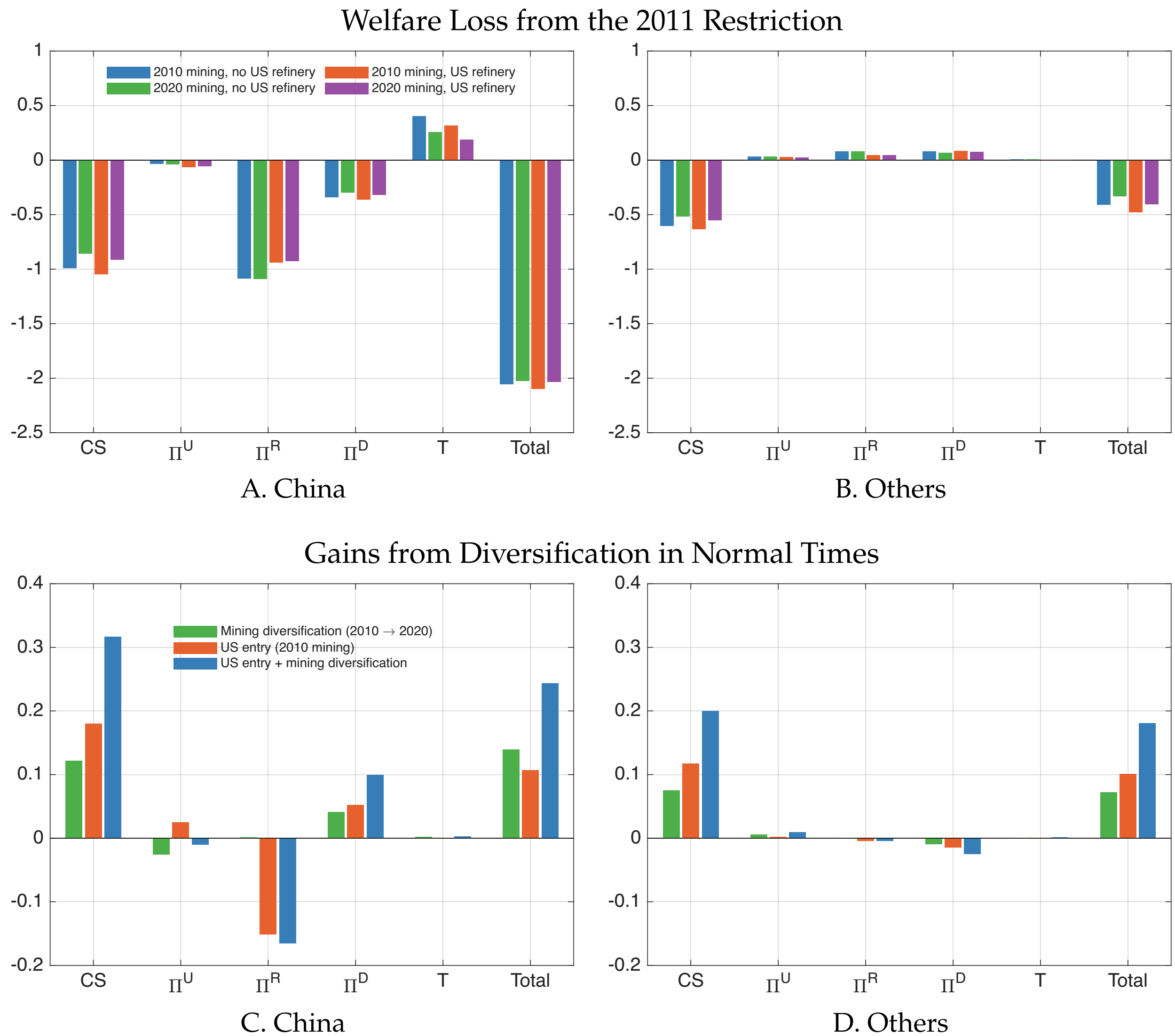
Figure D.1: Mining Productivity. 2010 vs. 2020



A. Mining Productivity A_n^U B. Mining Production (Data)

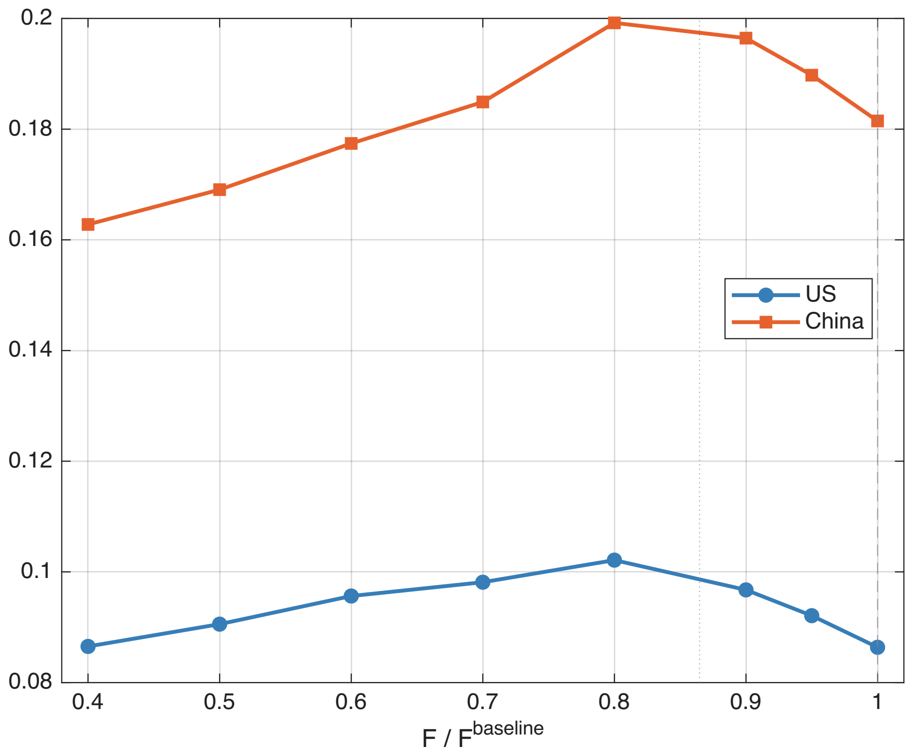
Notes. This figure reports the cross-country mining distributions behind the diversification counterfactual. Panel A reports the mining productivities A_n^U that the model backs out from mine production, where the 2020 values come from the baseline calibration and the 2010 values are recalibrated to pre-2011 mine production, averaged over 2000–2010, holding all other fundamentals fixed. China's productivity is normalized to one in Panel A, which is drawn on a log scale. Panel B reports mine production shares in the data.

Figure D.2: US Supply Chain Diversification, Mining versus Refining. China and Other Countries



Notes. This figure reports decomposition of the welfare effects of US supply chain diversification in mining and in refining, for the US. Panels A and B report the effects of China's 2011 export restriction under four combinations of the mining distribution and US refinery entry for China and Others, respectively. Panels C and D report the gains from mining diversification, from US refinery entry, and from the two together in normal times for China and Others, respectively. US refinery entry is exogenous in all panels. In Panels C and D, the subsidy cost is not subtracted in fiscal transfer T, as we do not model any subsidy cost for mining diversification.

Figure D.3: Sensitivity Checks over the Fixed Entry Cost



Notes. This figure reports the welfare effects of the calibrated US subsidy under alternative calibrations of the fixed entry cost F. In the baseline, F is calibrated to the break-even level for US entry given the observed subsidy-to-sales ratio of 20%. In the alternatives, F is set to fractions 0.9 through 0.4 of the break-even level. The dashed vertical line marks the baseline and the dotted vertical line marks the level below which US entry would be profitable even without the subsidy. Welfare effects are expressed in percent of each country's downstream revenue.

References (Appendix)

IEA, "Global Critical Minerals Outlook 2024," Technical Report, International Energy Agency, Paris 2024.