Policy Responses to Rare Earth Element Supply Shocks

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INTRODUCTION

The United States' dependence on foreign sources for REE has been an important topic at the nexus of energy policy, economic policy, and national security for over a decade (Grasso 2013; Gholz 2014). REE dependence typically refers to the percentage of domestic REE consumption that is imported. In 16 of the past 20 years, the U.S. has imported 100% of its consumption of rare earth metals.

Most of the impetus for concerns about U.S. REE dependence center on China and its potential ability to influence world REE markets to the detriment of U.S. interests. From 2001-2019, nearly 85% of U.S. (apparent) REE consumption was imported, primarily from China, which produces most of the world's REOs and has more lenient labor and environmental regulations regarding the separation of REE from mined ores. This creates lower costs that allows China to capture a large share of the REE market (Grasso 2013). Import reliance exposes U.S. manufacturers to costly supply disruptions. For example, the 2010-2014 Chinese REE export restrictions sharply increased REE prices, triggering new U.S. REO production and temporarily lowering U.S. reliance on REE imports (Figure 1).
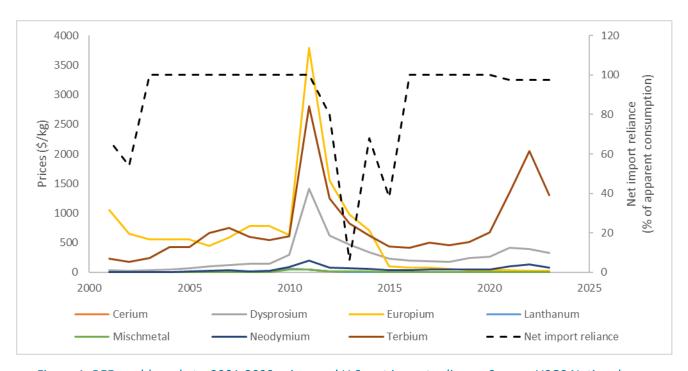

Figure 1: REE world markets, 2001-2023 prices and U.S. net import reliance. Source: USGS National Minerals Information Center, Rare Earths Statistics and Information, Annual Publications, Rare Earths; USGS Metal Prices in the United States Through 2010, Scientific Investigations Report 2012-5188

While REE dependence is straightforward to estimate, far less is known about the cost of this dependence. REE security cost refers to the loss of economic welfare that may arise from the U.S. consuming REE from foreign sources. REE security costs exceed the actual expenditures on REE imports due to market failures that plague world REE markets. For example, in 2019 the U.S. imported all of the $170 million in REEs it consumed from China, Estonia, Japan and Malaysia (lanthanides); Europe, China, Japan and Russia (Sc); and China, Estonia, Republic of Korea and Japan (Y) (Gambogi 2020). However,

due to these security costs, the true cost of REE imports exceeded $170 million, perhaps by a large margin. Importantly, these security costs are not reflected in the price that U.S. importers and consumers pay for foreign-produced REE causing the U.S. economy to over-rely on foreign imports and undervalue domestic production.

Market failures suggest world REE markets are inefficient and this inefficiency signals that gains to the U.S. economy could be achieved by intervening in world REE markets to reduce overall U.S. REE intensity, discourage REE imports, encourage domestic REE production, and/or create a strategic REE stockpile. Large estimates of the U.S. REE security cost provide a strong economic justification for these interventions in world REE markets. Different types of security costs can also be estimated to provide insight about the effectiveness of different policies for achieving a range of domestic objectives.

This report discusses how U.S. REE security costs capture the economic costs of REE dependence, provides initial estimates of these costs for the U.S. and G10 countries, considers how these security costs can be used to inform policy, and identifies a research agenda to address critical knowledge gaps.

What security costs tell us about the impact of foreign reliance on REEs

REE security costs would be accurately defined as the costs that arise when prices are an imperfect signal of the true cost of imported REE on the U.S. economy. The imperfect signal sent by global markets causes U.S. manufacturers to use too much REE, over-rely on foreign imports, and underinvest in securing their supply chains. Security costs can generally be broken into two categories:

1.) **Income or wealth transfers between market participants.** Wealth transfers affect the distribution of the world's REE wealth but do not alter the efficiency of the markets. In other words, wealth transfers alter the way the gains from trade are split between buyers and sellers but does not alter the size of the gains from trade itself. These wealth transfers may be an unintended byproduct of a market failure.

2.) **The inefficiencies generated when a market failure occurs.** If the value of the world's REE reserves are viewed as a pie, inefficiencies would imply shrinking the pie. Since value captures elements of both supply and demand for REE, shrinking the pie harms both producers and consumers of REE. These inefficiencies are often referred to as a deadweight loss since all market participants are harmed. These market inefficiencies can originate from two sources:

   a. *World REE markets*. For instance, imperfectly competitive world REE markets can lead to a loss of U.S. potential GDP. All costs that arise from imperfectly competitive world REE markets should be included in REE security cost estimates.

   b. *Related capital and labor markets*. For example, supply shocks may lead to losses in efficiency that would warrant inclusion in REE security cost estimates. Supply shocks alone would not constitute a market failure. But market failures elsewhere in the economy may limit capital and labor adjustments in response to the shock. A supply shock could also constitute a market failure if it was the result of deliberate exercise of market power by China. Thus, the argument for considering supply shocks in REE security cost estimates relies on both incomplete and imperfectly competitive markets.

REE security costs could therefore be interpreted as the losses generated by market inefficiencies or changes in the distribution of income between U.S. consumers and producers and foreign REE producers. Typically, the former category of costs typically serves as the basis for market interventions. However, the latter cost category (a redistribution of income) may still be a concern for U.S. policymakers since they involve wealth transfers out of the U.S. Wealth transfers are often viewed as pecuniary externalities since these transfers do not compromise the efficiency of world REE markets and may actually be necessary forces to ensure efficient world REE markets. This distinction explains some unnecessary confusion and conflicting policy prescriptions aimed at addressing U.S. REE dependency.

To avoid this confusion, Figure 2 provides a typology of potential components that may be included in REE security cost estimates. The typology first distinguishes between pecuniary externalities (changes in the distribution of income that do not affect REE market efficiency) and efficiency losses originating from the most common market failure cited for REEs – supply-side market power. Pecuniary externalities arise from changes in the terms of trade during stable market conditions due to noncompetitive REE supply (Type 1). Efficiency losses are disaggregated into those originating from market failures in the world REE market (Types 2 and 3) and market failures in other capital and labor markets (Types 4 and 5). Type 3 and 4 cost components can be used to estimate the size of tariff on REE imports to the U.S.. Types 4 and 5 become critical when assessing the size and management of a strategic REE stockpile.
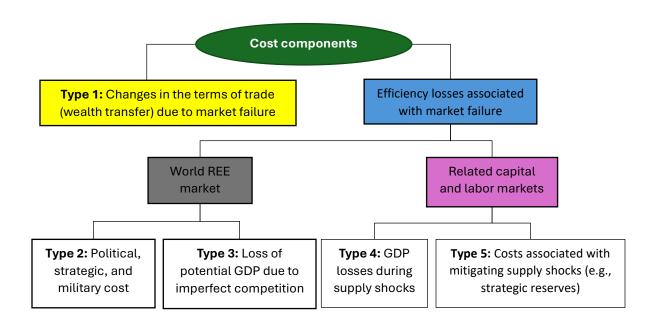

Figure 2. Typology of REE security cost estimates

Figures 3 and 4 illustrate how security costs can be used to inform policy. Figure 3 shows the amount of REE consumed by the U.S., the amount imported from China and the amount imported from the rest of the world (ROW) given three basic factors: 1) U.S. demand for REE which is determined by U.S. companies' willingness to pay to secure REE for production, 2) the long-run supply of REE from the ROW (including domestic producers), and 3) the world price. A Chinese embargo on REE exports to the U.S. would force the U.S. to rely only on ROW imports. This supply shock would both restrict U.S. supply

and increase prices. In the long-run, the U.S. would be forced to rely on non-Chinese producers and the cost of importing would rise above the pre-embargo world price according to the long-run ROW supply curve in Figure 3. However, non-Chinese production will not be able to come online immediately. In the short-run immediately following the embargo, the U.S. must rely on the production capacity before the embargo resulting in a perfectly vertical (inelastic) supply curve. The resulting short-run impact on the U.S. economy is represented by the shaded area in Figure 3.
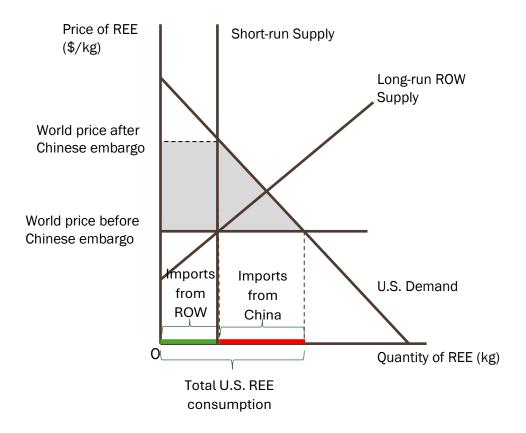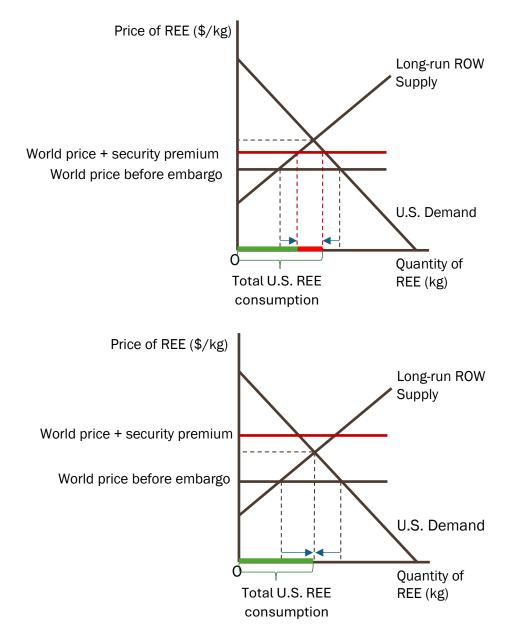

Figure 3. Economic impacts of a Chinese embargo on U.S. producers and consumers depend on U.S. demand, rest-of-the world supply and the world price

The timing and magnitude of REE embargos are not certain. Thus, the shaded area is an overestimate of the potential benefits of a domestic critical mineral supply chain. Instead, we can use the security costs in Figure 2 to create a security premium that, when added to the world price of REE, fully reflects the cost incurred by U.S. producers and consumers due to REE import dependence. The various security cost components in Figure 2 indicate that the world REE price will not reflect the true marginal cost of REE imports incurred by the U.S. economy. The security premium represents the security-related costs to the U.S. economy that U.S. importers fail to recognize when making import decisions. In short, including the security premium in the world price of REE would cause U.S. importers to fully account for the security risk that U.S. dependence on foreign sources implies.

Figure 4A shows how the inclusion of a relatively small security premium impacts imports and the source of imports. A small security premium raises the REE price which triggers a reduction in U.S. REE consumption, a reduction in Chinese imports, and an increase in ROW imports and domestic production. The larger security premium in Figure 4B would provide an economic justification for REE independence from China, and expansion of imports from friendly ROW countries, and an expansion of domestic production. Thus, a key goalpost for any U.S. REE policy is an estimate of the U.S. security premium based on the best available data.

Figure 4. *How U.S. REE security premiums can be used to guide U.S. policy. Small premiums provide an economic justification for a reduction in Chinese imports, an increase in imports from partner countries, and an expansion of domestic production (top panel). Larger premiums provide a justification for complete independence from Chinese imports (bottom panel).*

How large are U.S. REE security premiums?

Using a method developed to estimate U.S. oil security premiums (Brown and Huntington 2013), we have developed the first estimates of U.S. REE security premiums. These estimates, which correspond to the Type 4 cost component in Figure 2, represent only a part of the total U.S. security costs. We estimate these security premiums for the U.S. and G10 countries to provide important context. Details and methods and data are described in Prakash and Sims (2025). As shown in Table 1, these countries vary in GDP, REE imports and import reliance on China.

Table 1. Reliance on imported REE and Chinese import reliance. Average from 1995-2023

Country	GDP (billions $)	REE Imports (metric tons)	% imported from China
United States	15,450.34	660.402	78.6
Canada	1,355.89	38.595	56.0
Japan	4,914.03	6,276.623	76.3
Germany	3,251.42	388.732	69.7
France	2,308.08	311.485	54.4
Italy	1,831.90	131.918	41.3
UK	2,447.88	154.234	49.7
Belgium	430.15	195.675	88.7
Netherlands	750.28	282.312	69.7
Sweden	443.95	46.914	4.5
Switzerland	548.94	3.216	72.3

Our Type 4 security premiums are based on three estimates of the dynamic adjustments in the economy and the likelihood of a REE supply shock. These estimates are presented in Table 2 and discussed below.

1) REE demand elasticity: The demand elasticity measures the change in REE demand in response to an increase in prices. Demand response to an increase in price can be either elastic (elasticity greater than -1) or inelastic (elasticity less than -1). The more inelastic demand, the less U.S. companies are able to transition to other sources of REE supply when prices increase. This inability to transition to other sources increases the REE security premiums. The U.S. REE demand elasticity is -0.199 which indicates that a 1% increase in REE prices corresponds with a 0.199% decrease in U.S. imports. This is slightly more inelastic than recent demand elasticity measures for Gallium and Germanium (Nassar e al. 2024).

2) REE income elasticity: The income elasticity measures the change in REE imports in response to a 1% increase in GDP. Demand response to an increase in GDP can be either elastic (elasticity greater than 1) or inelastic (elasticity less than 1). The more elastic demand, the more economic growth is tied to REE imports and the larger REE security premiums. The U.S. income elasticity is 7.29 which indicates that a 1% increase in U.S. GDP corresponds with a 7% increase in U.S. imports.

3) Probability and magnitude of REE supply shocks: We use three criteria to identify REE supply shocks in the trade data. We then categorize these shocks into small (20-50% decline in Chinese supply), medium (51-90% decline in Chinese supply), and extreme (>90% decline in Chinese

supply). Using a Bayesian conditional probability, we calculate the probability of each size shock for each country.

Table 2. Critical factors of Type 4 REE security costs, 1995-2023

Country	REE demand elasticity	REE income elasticity	Probability no REE supply shock	Probability >90% decline in REE imports	Type 4 REE security cost ($/kg)
United States	-0.199	7.288	93.10	0	$6.67
Canada	-0.997	2.191	79.38	3.45	$4.47
Germany	0	-1.063	82.80	0	$0.89
France	-0.310	0	85.77	2.87	$9.41
Italy	-0.961	0	69.1	13.78	$5.89
Japan	-0.9	0	96.56	0	$0.09
UK	-0.439	0	86.30	0	$2.94
Switzerland	-1.071	0.652	86.22	6.89	$9.19
Netherlands	-0.414	0	86.30	3.43	$3.98
Sweden	0	0	89.67	3.44	$0.00
Belgium	-2.143	0	86.25	3.45	$1.17

The countries with the highest REE security premiums are France ($9.41) and Switzerland ($9.19). France has a high security premium due to inelastic REE demand and a relatively large probability of an extreme REE supply shock. Switzerland has more elastic REE demand but the second highest probability of an extreme REE supply shock. The U.S. has the third highest REE security premium even though it has a smaller probability of larger REE supply shocks than other countries. The economic cost of U.S. dependence on foreign sources of REE stems from its inelastic demand and high income elasticity. Italy has the fourth highest REE security premium largely due to the high probability of extreme REE supply shocks. All other countries have a security premium less than $5/kg. For instance, Japan has nearly 10 times the REE imports of the U.S.. However, its security premium is less than $1/kg because its demand is more elastic than the U.S. and it experiences fewer supply shocks.

The U.S. REE security premium is equal to 25% of the U.S. import price (2023$). In contrast, estimates of similar security premiums for U.S. oil imports are 5-6% of the U.S. import price adjusted to 2023 U.S. dollars. The reason for the higher cost of REE import reliance is that U.S. REE supply shocks are larger and more likely than oil shocks. Since the U.S. imports far more oil than REE, the total cost of U.S. reliance on oil imports remains larger than the total cost of U.S. REE import reliance. However, since import decisions are made at the margin, the larger REE security premiums indicate that the security implications of import reliance are causing a larger distortion in REE import decisions than in oil import decisions. As the importance of REE to the U.S. economy increases, this distortion in import decisions will increase GDP losses and expected import costs.

Policy responses

The large U.S. REE security premiums in Table 2 suggest the U.S. is particularly susceptible to an unexpected drop in REE imports from other countries. The magnitude of the U.S. security premium also motivates federal intervention in global REE markets. There are 4 main policy responses to address the susceptibility captured in the security premiums in Table 2:

1) *Subsidize ROW or domestic REE production.* This strategy would increase the long-run ROW supply curve resulting in more imports from the ROW and less from China (see Figure 5). This strategy could provide economic growth in areas with mining and processing capacity but also drains domestic REE reserves faster. China also has excess processing capacity and could flood the market in response. Flooding the market with Chinese REE would lower global prices forcing many U.S. companies to close and allowing China to regain market share.
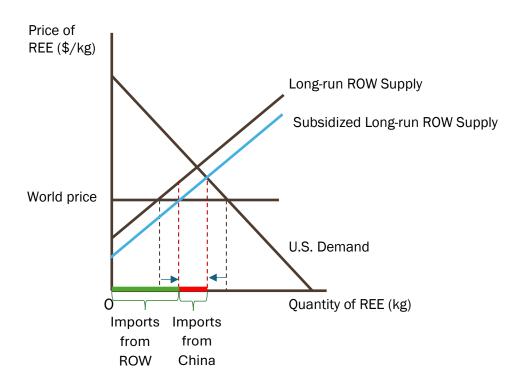
Figure 5. Impact of subsidizing ROW and domestic REE production

2) *Impose tariff or quota on Chinese imports.* Imposing a tariff would raise U.S. prices above world prices resulting in an increase in domestic production and imports from the ROW and a decrease in imports from China (see Figure 6). The U.S. federal government would collect revenue. U.S. REE producers would benefit from higher domestic prices while U.S. consumers would be harmed through higher prices. Imposing a quota produces a similar outcome to imposing tariffs. U.S. REE producers would benefit from higher domestic prices while U.S. consumers would be harmed through higher prices. The major difference is that additional revenue is captured by importers and not the government.
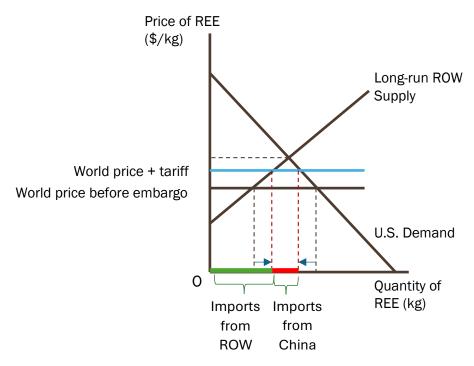
Figure 6. Impact of imposing tariff on Chinese imports

3) *Invest in a REE stockpile similar to the strategic petroleum reserve (SPR).* Stockpiling REE can be a viable short-term strategy to mitigate price volatility and supply disruptions (Toman and Macauley 1986). Stockpiling can also serve as a strategic tool for long-term price dampening given the current degree of market concentration in the global REE market (Nichols and Zeckhauser 1977, Wolf 2022). While the U.S. currently has limited stockpiles for defense purposes, this strategy would expand the stockpile to consider non-defense uses for REE. The U.S. would release supplies from the stockpile in the event of an unexpected decrease in REE imports. These releases would mitigate the increase in prices depending on how the stockpile was managed. Stockpile releases could be used to hold prices at pre-embargo levels. However, the large releases needed to hold prices steady could only be sustained for a short period of time. Another stockpile management strategy would be to use releases to mimic the long-run ROW supply (see Figure 7). This strategy would result in a modest increase in prices but could be sustained for a longer period of time and would maximize the total economic value of the stockpile. The benefits of a stockpile decline as tariffs and domestic production subsidies reduce imports and increase domestic production. Thus a stockpile is a substitute for these other policy options and not a complement (McGuire 2006).
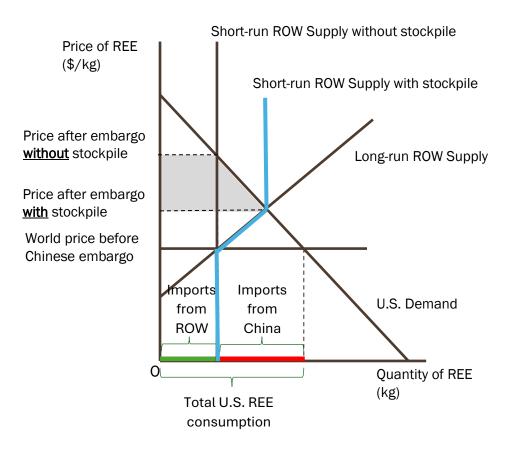
Figure 7. REE stockpile reduces the economic impacts of an REE supply shock

Considerations for U.S. policy on REE

The relative merits of these three policy options are poorly understood for REE. However, the research spurred by the U.S. experience with oil embargoes and OPEC provides some insight that may apply to U.S. REE policy. Based on the existing research on oil and energy security, I have identified three questions that must be addressed to assess the relative merits of the three policy options outlined above as they pertain to REE:

1) ***What is our best available understanding of the macroeconomic cost of U.S. dependence on REE imports?*** Estimates of all the security costs in Figure 2 are needed to answer this question. Table 2 provides initial estimates for the Type 4 security costs. Type 2 security costs are difficult to estimate. However, Type 3 costs are possible to estimate and, based on the U.S. experience with oil, will be large.

2) ***How large would a U.S. REE stockpile need to be and how should it be managed?*** To answer this question, we must compare the costs and benefits of a stockpile of various sizes. A stockpile has two costs. First is the cost of building, filling, and maintaining the stockpile itself. We expect this cost to be small relative to the U.S. private industry experience with oil and gas stockpiles. The second is the opportunity cost of holding the critical minerals in reserve. This opportunity

cost is the difference in the current price and the future price when that unit is sold. Assessing these two costs would provide estimates of the Type 5 REE security costs in Figure 2. The benefits of a stockpile are the reduction in GDP losses and REE import costs during supply shocks. Price stabilization from strategic REE stockpiling may provide benefits to risk-averse agents by reducing income risks induced by fluctuating REE prices. Key factors influencing the benefits and costs of a critical mineral stockpile are:

a) REE demand elasticity
b) REE income elasticity
c) Probability and severity of supply disruptions
d) GDP elasticity with respect to REE price shocks
e) REE supply elasticity

In Table 2, we provide the first estimates of (a)-(c) for a basket of REE. The data exists to provide similar estimates for other critical minerals. Estimates for (d) and (e) are also possible but will require alternative statistical techniques and data sources. These benefits and costs can be weighed using a dynamic programming approach which will provide insights on the optimal acquisition and sale strategies for the U.S. REE stockpile and the degree to which these management decisions can stabilize world prices (Teisberg 1981).

3) ***What incentives (if any) do private companies and other countries have to stockpile REE?*** In a global REE market, the federal government's strategic stockpile decisions can be affected by the decisions of private companies and other countries (Zhang et al. 2017). There is no incentive for companies to stockpile if the REE market satisfies the efficient market hypothesis. The various market failures in the global REE market become the root of all incentives for companies and countries to stockpile REE. Markets don't exist for supply and price insurance for REE so companies and other countries may stockpile REE as an alternative to the ideal insurance policy. Price stabilization from strategic REE stockpiling may provide benefits to risk-averse agents by reducing income risks induced by fluctuating REE prices – a stockpile risk reduction premium. However, the risk reduction premium can differ significantly for public and private oil inventories (Toman and Macauley 1986) suggesting that the U.S. government incentives to stockpile REE may diverge from private company incentives to develop similar stockpiles. Production smoothing is one motivation for stockpiling REE but it requires sufficient price volatility. Mason (2011) shows that production smoothing is a more likely explanation for private oil inventories than oil market speculation. A better understanding of the incentives of other countries to stockpile resources can serve as a basis for identifying members of a U.S.-led international agreement to stabilize REE markets (Devarajan and Weiner 1989).

Conclusions

The U.S. import reliance on REE is an important topic at the nexus of energy policy, economic policy, and national security. However, the economic cost of this import dependence is poorly understood which is limiting the ability to craft cost-effective U.S. policy to combat this import dependence. In this report we provide evidence that the economic cost of this REE import dependence is larger than most other G10 countries and larger than the security costs generated by U.S. dependence on foreign oil imports (in marginal terms). These estimates provide an economic motivation for the federal government to stockpile REE metals. The report also highlights important information gaps that must be addressed to develop and manage a strategic REE stockpile and to evaluate the effectiveness of a stockpile relative to other policy approaches such as domestic production subsidies and import tariffs.

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