Critical Minerals, Electric Goods, Geopolitical Risk, and the Global Energy Transition

Macroeconomia Aplicada

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Countries are actively pursuing the energy transition, yet this process carries geopolitical consequences. Our paper delves into this dynamic by analyzing the implications of Chinese exports of critical electrical goods and geopolitical risk on national energy transitions, lithium and rare earth production and prices, and oil prices. We adopt a Global Vector Autoregressive (GVAR) model from July 2012 to December 2019 across 12 economies, with a focus on Australia (due to its near-monopolistic position in lithium), China (nearly monopolistic in rare earth), and the U.S. We construct a theoretical model that shows how Chinese geopolitical risk affects i) consumption of electrical goods, ii) renewable energy, and iii) critical minerals (lithium and rare earth). Our empirical model validates these three hypotheses. We found that Chinese exports of electrical goods create a dependency in other economies, making them reliant on the Chinese energy matrix. Furthermore, our findings show that Chinese geopolitical risk affects electrical goods consumption, energy matrices, and critical minerals through direct and indirect channels. While oil prices are generally not pivotal for the energy transition of most economies, the U.S. stands as a unique case where oil prices are essential to understanding its energy matrix and critical minerals production. We discuss the implications of our results, which suggest the potential for geopolitical tensions and the possibility of international cooperation to advance the energy transition.

Keywords: Energy transition; Lithium; Rare Earth; Geopolitical risk; Oil prices; China.

JEL Code: Q4; Q43; F41.

Países estão ativamente buscando a transição energética, mas este processo tem consequências geopolíticas. O nosso artigo investiga esta dinâmica, analisando as implicações das exportações chinesas de bens elétricos críticos e do risco geopolítico nas transições energéticas nacionais, na produção e nos preços do lítio e de terras raras, e nos

preços do petróleo. Adotamos um modelo GVAR de julho de 2012 a dezembro de 2019 em 12 economias, com foco na Austrália (devido à sua posição quase monopolista em lítio), na China (quase monopolista em terras raras) e nos EUA. Construímos um modelo teórico que mostra como o risco geopolítico chinês afeta i) o consumo de bens elétricos, ii) energia renovável e iii) minerais críticos (lítio e terras raras). Nosso modelo empírico valida essas três hipóteses. Os resultados mostram que as exportações chinesas de produtos eléctricos criam uma dependência nas outras economias, tornando-as dependentes da matriz energética chinesa. Além disso, as nossas conclusões mostram que o risco geopolítico chinês afeta o consumo de bens elétricos, as matrizes energéticas e os minerais críticos através de canais diretos e indiretos. Embora os preços do petróleo não sejam cruciais para a transição energética da maioria das economias, os EUA constituem um caso único onde os preços do petróleo são essenciais para a compreensão da sua matriz energética e da produção de minerais críticos. Discutimos as implicações dos nossos resultados, que sugerem o potencial para tensões geopolíticas e a possibilidade de cooperação internacional para avançar na transição energética.
Palavras-chave: Transição energética; Lítio; Terra Rara; Risco geopolítico; Preços de petróleo.

1. Introduction

What are the global economic and geopolitical impacts caused by China’s significant strategic control of the global upstream and downstream electricity supply chain? How do China’s geopolitical efforts (e.g., military strategies and maneuvers) contribute to China’s positioning as a global leader in the production of critical minerals and electric goods? This paper addresses these questions.

A recent article in The Economist raised the following intriguing question: “Can Australia break China’s monopoly on critical minerals?” (The Economist, 2023). Critical minerals are essential inputs in the energy transition from fossil fuels to electrification. A recent (April 2024) White Paper called “Energy Transition and Geopolitics: Are Critical Minerals the New Oil?”, published by the World Economic Forum, starts by asking the following important question: “How likely is it that the clean energy transition, advancing rapidly in much of the world, could replace dependence on oil and other hydrocarbons by dependencies on critical minerals?” (p. 4) The authors provide a positive response to the question and then ask another important question: “…will this shift in dependencies be bad news for geopolitics, energy security or the environment?” (p. 4) The paper considers issues related to supply, demand, market concentration, and market manipulations by governments, and provides an optimistic perspective for the dependencies on critical minerals relative to past and current dependence on oil. The argument relies on lower, observed and forecasted, market manipulations by governments (except for China), on technological improvements to be had in mining operations, on demand-side efficiency in consuming electricity with lower utilization of critical minerals, on recycling, and on demand substitution.

The White Paper, however, does not consider: (i) the strategic choices that China can or has already made to expand its significant economic and geopolitical control of the electricity supply chain; and (ii) does not estimate (econometrically) relevant global impacts associated with such a dominant economic and geopolitical position. This paper fills the gaps. To our knowledge, we are pioneers in this regard.

We build a simple differential game to capture China's dominant position and its strategies to enhance this position. In our dynamic game-theoretic model, there are two players, China, and the rest of the world (ROW). China is the leader. It influences production of critical minerals through geopolitical efforts. It anticipates, however, that production of critical minerals and consumption/production of electric goods are positively linked intertemporally due to the formation of deep habits in the ROW's consumption of electric goods. The ROW faces geopolitical risk associated with China's influence on the production of critical minerals. The model clearly shows that, in the steady state, production of critical minerals, production/consumption of electric goods and China's geopolitical effort are essential fuels in the promotion of the global energy transition. The model also enables us to conduct a comparative statics exercise with respect to various important parameters (exogenous variables), including a proxy for the geopolitical risk that the ROW faces. The complex, non-linear, relationships among the endogenous variables do not yield unambiguous comparative statics results. The empirical model enables us to establish positive or negative relationships for some of the exogenous shocks, as we describe below.

The theoretical model generates three hypotheses: 1) the relationship between Chinese geopolitical risk and the consumption of electrical goods; 2) the influence of Chinese geopolitical risk on renewable energy (energy matrix); and 3) the effect of Chinese geopolitical risk on critical minerals (such as lithium and rare earth elements), which are econometrically tested using a Global Vector Autoregressive (GVAR) model. GVAR connects economies through bilateral trade and simulates the world economy using foreign variables. Consequently, GVAR enables us to explore how Chinese exports of electrical goods and geopolitical risk affect other economies, particularly key players in the energy transition process, such as Australia and the U.S. The Chinese government's control over global production/exports of electrical goods is evidenced, for example, by very large subsidies that it provides to production of electric vehicles (see, e.g.., https://asia.nikkei.com/Spotlight/Electric-cars-in-China/China-gives-EV-sector-billions-of-yuan-in-subsidies).

We illustrate China's geopolitical risk (GPR) using the index developed by Caldara and Iacoviello (2022). This index measures the frequency of geopolitical tensions reported in selected newspapers. For our purposes, the GPR is derived from two relevant categories: war threats and military buildups. In other words, the GPR reflects the actions that countries take in these areas. By using the GPR, we incorporate the escalation of geopolitical tensions into our econometric model. Furthermore, we can link China's geopolitical efforts to international energy transitions.

We show that China’s increasing exports of electrical goods are critical factors that drive the growth of demand of critical minerals. In addition, the limited current supplies of critical minerals yield a confluence of forces that may be bad news for geopolitics and energy security in a future in which the energy sector is dominated by electricity. As the White Paper above argues, the bad news may be averted by smart and effective policies that diminish/prevent supply concentrations and favor efficient demand utilization, recycling, and demand substitution.

If the future is electric, as most nations presume, control over precious critical minerals may provide the controllers with enormous wealth and geopolitical power. Furthermore, an electric future becomes ever more certain as the world becomes increasingly more dependent on the consumption of intermediate and final electric goods. Selective intertemporal consumption dependence/persistence follows from the formation/persistence of deep habits, as clearly demonstrated by Ravn et al (2006). Particularly aligned with the motivation for this study is the finding in Ravn et al. (2006) that deep habits produce intertemporal incentives for imperfectly competitive producers to anticipate that future demands for their products are positively linked to current sales. This follows because future consumption levels of goods characterized by deep habits are positively related to current consumption levels. In our context, the theoretical implication is that producers and exporters of critical minerals and producers and exporters of electric intermediate and final goods have mutually reinforcing and dynamic incentives to pursue complementary, procyclical, strategies. The fact that producers and exporters of critical minerals and producers and exporters of electric goods have complementary strategies follows from technological considerations, which do not imply an intertemporal linkage. *The dynamic linkage is implied by deep habits*. As the world becomes more dependent on the consumption/utilization of electric goods during the energy transition (see Figures A and B in the appendices), the world also becomes more dependent on the consumption of critical minerals.

The history of the oil industry teaches us that a country with abundant production and reserves of oil enhances its geopolitical influence (Yergin, 2011). The transition to renewable energy presents similar incentives and opportunities. Together, the natural objectives of political aggrandizement and wealth maximization, manifested in the article cited in the first paragraph, enable us to derive a rational hypothesis: *nations that have abundant reserves of critical minerals or have comparative advantage in the production of electric goods should exert greater geopolitical efforts to maintain or expand their favorable relative positions in the global arena during the energy transition*. China, a nation that is well endowed with critical minerals and that commands the world markets in electric goods, is, perhaps, the nation that has the strongest incentive to "fuel" the energy transition in the world!

Our premise regarding China's motivations to exert efforts to increase its dominant position in the global energy spectrum is backed by recent political-science literature (see, e.g., Markowitz et al. (2019) and Markowitz (2023)). Markowitz (2023) shows that resource-abundant states, which are dependent on the income produced by exploration of resources, have the strongest incentives to secure control over such resources as long as global markets offer resource-scarce states access to limited resources. We contribute to his reasoning by also including control over exports of highly desirable tradeable goods (i.e., electric goods).

We delve into the intricate relationships among the energy transition, exports/imports of electric goods, production of critical minerals, and geopolitics. As Blondeel et al (2024) points out, it is necessary to integrate geopolitics into scientific models that examine future implications of interactions among energy systems, international politics, and economics. Our analysis examines the influence of Chinese exports of electric goods on production and pricing of rare earth and lithium, oil prices, and domestic energy transitions. We hypothesize that Chinese exports lead to a dependence of other countries on the importation of these goods, thereby inducing changes in their energy matrices and the production of critical minerals.

As we mentioned above, we adopt the GVAR model in our econometric investigation. We utilize data from July 2012 to December 2019 across 12 economies. Another characteristic of GVAR is its ability to individually model economies, allowing us to capture spillover effects from China on the domestic energy matrix and lithium and rare earth production. Furthermore, we can also demonstrate how a Chinese shock affects global variables, such as oil and critical mineral prices. In short, GVAR accommodates our analysis by creating a system of open economies connected through economic and non-economic variables.

Our results demonstrate that China impacts the consumption of electrical goods, renewable energy, and the production of critical minerals across economies through its exports of electrical goods and geopolitical risk. Additionally, we found that these exports and Chinese geopolitical risk influence international prices (lithium, rare earth, and oil). Therefore, our estimates highlight China's influence on the energy transition process and related markets.

We constructed two models for critical minerals, one focused on Australia (lithium) and another on China (rare earth). The results indicate that these critical minerals predominantly affect countries where they hold a dominant position. Additionally, uniquely for the U.S., oil prices exert a significant influence on its economy, particularly on its energy matrix.

The energy transition is a topic that has gained growing attention from policymakers, politicians, and analysts. In the national sphere, one challenge is to reconcile the interests and objectives of several sectors towards a common goal (Leach, 1992; Chang et al., 2021). Tian et al. (2022) discuss the challenges of involving energy transition, such as the implementation of policies to disincentivize fossil fuel production while promoting the production of renewable energy. York and Bell (2019) argue that changes in the energy matrix do not imply the end of old forms of energy; energy transition could be described instead as energy addition. One example to reinforce this conclusion is the rise of oil as the main energy source in the twentieth century: coal lost space but continued to be produced. In other words, energy from oil was an addition to the energy matrix, without ending the production of coal.

We complement these investigations by including elements of old forms of production (oil), energy matrices, and inputs to advance the energy transition (critical minerals). We construct a model that shows the result of interactions between these variables. Consequently, we analyze how fossil fuels and critical minerals respond to the energy transition. While Leach (1992) and Chang et al. (2021) discuss potential ways of cooperation to achieve energy transition, by including 12 economies in our model, we provide empirical evidence of potential international cooperation. Additionally, we present scenarios involving potential geopolitical tensions, complementing the investigation by Su et al. (2021), who argue that energy transition reduces geopolitical risks.

Khan et al. (2021) analyzes the relationship between energy transition, economic growth, and energy consumption in panel data from 38 economies. Zhang and Kong (2022) study Chinese companies and demonstrate that policies promoting energy transition increase their productivity. These studies advance the literature by showing statistically significant relationships between energy transition and economic and non-economic variables. However, their econometric model does not capture spillover effects and heterogeneities. Panel data gives one coefficient to the whole sample. By using the GVAR, we construct models for each economy, allowing us to observe how domestic variables respond to shocks. Thus, we can find heterogeneities in the results and point out national specificities.

Considine et al. (2023) employ a Global Vector Autoregressive (GVAR) model to demonstrate how the critical minerals price index affects domestic inflation and oil prices. The authors also examine the impact of oil price shocks on these variables. In our study, we complement their research by: i) disaggregating the critical mineral price index into lithium and rare earth prices, ii) incorporating the production of lithium and rare earth, and iii) integrating energy matrices. Consequently, our framework allows for a comprehensive discussion of the implications of Chinese export policies on domestic energy transitions and the efforts involved in producing critical minerals. Moreover, it captures the influence of China on lithium, rare earth, and oil prices

In what follows, section 2 presents the theoretical model. Section 3 describes the methodology and data. Section 4 discusses the results. Section 5 concludes the study.

2. Theoretical Model

The model is a hierarchical differential game in which China is the leader and ROW is the follower. To emphasize the role that geopolitics play in the global arena, we assume that China does not possess direct control over economic variables (production or consumption). China’s sole control variable is its geopolitical effort (e.g., military activities). As described in the introduction, the statistic Chinese geopolitical risk that we utilize in the empirical model is positively correlated with China’s geopolitical effort.

China chooses geopolitical effort to maximize its net economic and geopolitical benefits from the energy transition. ROW consumes electric goods, develops habits of consumption, and produces critical minerals. As we demonstrate below, ROW's net benefits are related to the production of critical minerals, which is positively influenced by China's geopolitical effort.

The Follower's Problem

Backward reasoning implies that we should start our analysis by considering the follower's problem and strategic choice first.

Critical minerals are essential inputs to the production of electric intermediate and final goods. For simplicity, we assume that one unit of critical mineral leads to the production/consumption of one unit of electric goods. Let G denote the amount of geopolitical effort that China exerts to advance its geopolitical and economic position in the world. The general dynamic constraint describes how production of critical minerals varies over time:

$$\dot{M} = \alpha G(M - E) \tag{1}$$

where M is mineral production. Note that China's geopolitical effort has a positive influence on the evolution of production of critical minerals. The endogenous variable E is the amount produced/consumed of electric goods. The dot over a variable denotes its time derivative, e.g., $\dot{M} \equiv dM/dt$.

The representative follower (rest of the world) consumes electric goods and develops deep habits towards consumption. Consumption of electric goods and deep habits generate benefits. In addition, ROW faces the cost of producing critical minerals. Let $M^{1+\beta}$, $\beta > 0$, denote the cost function (strictly convex). The parameter β is technological. The lower the value for this parameter, the more advanced is the technology to produce critical minerals. ROW solves the following problem:

$$\max_{E} \int \left(\frac{E^{1-\sigma} h^{-\vartheta(1-\sigma)}}{1-\sigma} - M^{1+\beta}\right) e^{-rt} dt \tag{2}$$

subject to (1) and the evolution of electric goods' consumption habits:

$$\dot{h} = \rho(E - h) \tag{3}$$

where h denotes electric goods' consumption habits, $\sigma \in (0,1)$ is the coefficient of risk aversion, $\vartheta \in (0,1)$ is the habits index and $\rho > 0$ is the relative weight of electric consumption at different times. The smaller the ρ is the lower the importance placed on consumption in the recent past. The parameter $r > 0$ is the follower's rate of time preference; that is, the measure of ROW's impatience.

The Hamiltonian of the follower's problem is

$$J = \frac{E^{1-\sigma} h^{-\vartheta(1-\sigma)}}{1-\sigma} - M^{1+\beta} + \gamma \alpha G(M - E) + \mu \rho (E - h) \tag{4}$$

where γ and μ are the co-state variables [shadow prices] of M and h, respectively. The necessary and sufficient conditions for optimality include satisfaction of equations (1), (3), and

$$J_E = E^{-\sigma} h^{-\vartheta(1-\sigma)} - \gamma \alpha G + \mu \rho = 0 \tag{5}$$

$$J_{EE} = -\sigma E^{-\sigma-1} h^{-\vartheta(1-\sigma)} < 0 \tag{6}$$

$$\dot{\gamma} - r\gamma = -J_M = (1 + \beta) M^{\beta} - \gamma \alpha G \tag{7}$$

$$\dot{\mu} - r\mu = -J_h = \vartheta E^{1-\sigma} h^{-\vartheta(1-\sigma)-1} + \mu \rho \tag{8}$$

and the transversality conditions (see Kamien and Schwartz, 2012). Differentiating equation (5) with respect to time and using (1), (3), (7) and (8) yields a differential equation for the consumption of electric goods:

$$\dot{E} = \frac{E}{\sigma}\left\{\rho\vartheta\left(\sigma\frac{E}{h} + 1 - \sigma\right) + E^{\sigma} h^{\vartheta(1-\sigma)} [\rho\mu(\rho + r) - \alpha[\gamma\left(G(r - \alpha G) + \dot{G}\right) + (1 + \beta) M^{\beta} G]\right\} \tag{9}$$

China’s Problem

China derives economic and geopolitical benefits from the energy transition. It wishes to maximize its geopolitical position in the global arena. As the Stackelberg leader, China takes the dynamic constraints (1), (3) and (9) into account to solve the following problem:

$$\max_{G} \int \left(\aleph - \frac{\delta G^2}{2}\right) e^{-rt} dt \tag{10}$$

where China’s net benefit from geopolitical effort is captured by the term $\aleph - \frac{\delta G^2}{2}$: where $\aleph$ is a positive constant and $\delta G^2/2$ is the cost of geopolitical effort, with $\delta > 0$ representing the depreciation rate of geopolitical effort.

The Hamiltonian corresponding to China’s problem is:

$$\begin{aligned} J^L = {} & \left(\aleph - \frac{\delta G^2}{2}\right) + \gamma_L \alpha G(M-E) + \mu_L \rho(E-h) + \varphi_L \frac{E}{\sigma}\Big\{\rho\vartheta\left(\sigma\frac{E}{h} + 1 - \sigma\right) + \\ & E^{\sigma} h^{\vartheta(1-\sigma)}[\rho\mu(\rho + r) - \alpha[\gamma\big(G(r - \alpha G) + \dot{G}\big) + (1+\beta)M^{\beta}G]\Big\} \end{aligned} \tag{11}$$

where $\gamma_L, \mu_L, \varphi_L$ are, respectively, the shadow prices for China of *M, h* and *E.*

The necessary and sufficient conditions for optimality include satisfaction of equations (1), (3), (9), and the following equations:

$$J_G^L = -\delta G + \gamma_L \alpha(M-E) + \varphi_L \frac{1}{\sigma} E^{\sigma+1} h^{\vartheta(1-\sigma)}[-\alpha[\gamma\big((r - 2\alpha G)\big) + (1+\beta)M^{\beta}] = 0 \tag{12}$$

$$J_{GG}^L = -\delta + \varphi_L \frac{2\alpha^2\gamma}{\sigma} E^{\sigma+1} h^{\vartheta(1-\sigma)} < 0 \tag{13}$$

$$\dot{\gamma}_L - r\gamma_L = -J_M^L = -\gamma_L \alpha G + \varphi_L(\beta - 1)\frac{\alpha(1+\beta)}{\sigma} E^{\sigma+1} h^{\vartheta(1-\sigma)} G M^{\beta-1} \tag{14}$$

$$\begin{aligned} \dot{\mu}_L - r\mu_L = -J_h^L = \mu_L \rho - \varphi_L \frac{E}{\sigma}\Big\{-\rho\vartheta\left(\frac{\sigma E}{h^2}\right) + \vartheta(1-\sigma) E^{\sigma} h^{\vartheta(1-\sigma)-1}[\rho\mu(\rho + r) - \\ \alpha[\gamma\big(G(r - \alpha G) + \dot{G}\big) + (1+\beta)M^{\beta}G]\Big\} \end{aligned} \tag{15}$$

$$\dot{\varphi}_L - r\varphi_L = -J_E^L = \gamma_L \alpha G - \mu_L \rho$$

$$-\varphi_L \frac{1}{\sigma}\left\{\rho\vartheta\left(\sigma\frac{E}{h}+1-\sigma\right) + E^{\sigma}h^{\vartheta(1-\sigma)}[\rho\mu(\rho+r) - \alpha[\gamma\big(G(r-\alpha G)+\dot{G}\big) + (1\right.$$

$$\left. +\beta)M^{\beta}G]\right\}$$

$$-\varphi_L\frac{E}{\sigma}\left\{\rho\vartheta\sigma\frac{1}{h} + \sigma E^{\sigma-1}h^{\vartheta(1-\sigma)}[[\rho\mu(\rho+r) - \alpha[\gamma\big(G(r-\alpha G)+\dot{G}\big) + (1+\beta)M^{\beta}G)]\right\}$$

(16)

and the transversality conditions. Equations (12) and (13) are the first and second order conditions for maximization with respect to the control variable, China's geopolitical effort *G*. Equations (14)-(16) are the adjoint equations corresponding to the marginal impact of the costate variables *M*, *h* and *E* upon China's Hamiltonian (11)

In the next section, we focus and derive the steady-state equilibrium for China's geopolitical risk

The Steady State Equilibrium

We are now ready to examine the steady state equilibrium. In the steady state,

$$\dot{M} = \dot{h} = \dot{\gamma} = \dot{\mu} = \dot{E} = \dot{\gamma}_L = \dot{\mu}_L = \dot{\varphi}_L = 0\,. \tag{17}$$

Equations (1), (3), (7) and (8) in the steady state become:

$$\dot{M} = 0 \rightarrow E = M \tag{1'}$$

$$\dot{h} = 0 \rightarrow E = h \tag{3'}$$

$$\dot{\gamma} = 0 \rightarrow \gamma(\alpha G - r) = (1+\beta)M^{\beta} \rightarrow \gamma = \frac{(1+\beta)M^{\beta}}{(\alpha G - r)} \tag{7'}$$

$$\dot{\mu} = 0 \rightarrow \mu(r+\rho) = -\vartheta E^{1-\sigma}h^{-\vartheta(1-\sigma)-1} \rightarrow \mu = \frac{-\vartheta E^{1-\sigma}h^{-\vartheta(1-\sigma)-1}}{(r+\rho)} \tag{8'}$$

Using (1'), (3'), (7') and (8') into (5) yields

$$E = \left[\frac{(\rho+r)\alpha(1+\beta)G}{(\rho+r-\vartheta\rho)(\alpha G - r)}\right]^{1/[2+\beta-\sigma-\vartheta(1-\sigma)]} \tag{5'}$$

Equations (14) -(16) in the steady state become:

$$\dot{\gamma}_L = 0 \rightarrow \gamma_L = \varphi_L \frac{\beta}{(r+\alpha G)}\frac{\alpha(1+\beta)}{\sigma}E^{\sigma+1}h^{\vartheta(1-\sigma)}GM^{\beta-1} \tag{14'}$$

$$\mu_L \dot{=} 0 \rightarrow \mu_L = -\varphi_L \frac{E}{\sigma(\rho-r)}\left\{-\rho\vartheta\left(\frac{\sigma E}{h^2}\right) + \vartheta(1-\sigma)E^{\sigma}h^{\vartheta(1-\sigma)-1}[\rho\mu(\rho+r) - \right.$$

$$\left.\alpha[\gamma\left(G(r-\alpha G)+\dot{G}\right) + (1+\beta)M^{\beta}G]\right\} \tag{15'}$$

$$\dot{\varphi}_L = 0 \rightarrow \mu_L\rho - \gamma_L\alpha G =$$

$$-\varphi_L\frac{1}{\sigma}\left\{\rho\vartheta\left(\sigma\frac{E}{h}+1-\sigma\right) - r + E^{\sigma}h^{\vartheta(1-\sigma)}[\rho\mu(\rho+r) - \alpha[\gamma\left(G(r-\alpha G)+\dot{G}\right) + (1\right.$$

$$\left. + \beta)M^{\beta}G]\right\}$$

$$-\varphi_L\frac{E}{\sigma}\left\{\rho\vartheta\sigma\frac{1}{h} + \sigma E^{\sigma-1}h^{\vartheta(1-\sigma)}[[\rho\mu(\rho+r) - \alpha[\gamma\left(G(r-\alpha G)+\dot{G}\right) + (1+\right.$$

$$\left.\beta)M^{\beta}G)]\right\} \tag{16'}$$

Substituting (14’) and (15’) into (16’) makes the resulting equation to be linear in φ_L. So, without loss of generality we assume $\varphi_L = 1$.

Using (1’), (3’), (7’) and $\varphi_L = 1$ into (12) yields

$$E = \left[\frac{\delta\sigma(\alpha G-r)}{\alpha^2(1+\beta)}\right]^{1/[1+\beta+\sigma+\vartheta(1-\sigma)]} \tag{17}$$

Equation (17) provides a straightforward and important relationship between the quantity of electric goods and the level of geopolitical effort exerted by China. Combining this result with equations (1’) and (3’), we can affirm:

Behavioral testable hypotheses: *The quantity of electric goods increases with the quantity of geopolitical effort at a decreasing rate. Given equations (1’) and (3’), we also see that the quantity of critical minerals and habit increase with China’s geopolitical effort.*

Note that equations (5’) and (17) yield an expression that determines the equilibrium value of China’s geopolitical effort, *G**, as an implicit function of the parameters:

$$\left[\frac{\delta\sigma(\alpha G-r)}{\alpha^2(1+\beta)}\right]^{1/[1+\beta+\sigma+\vartheta(1-\sigma)]}\frac{(\rho+r-\vartheta\rho)(\alpha G-r)}{\alpha(\rho+r)(1+\beta)G} = 1 \tag{18}$$

Let $G^*(.)$ denote the implicit function defined by equation (18). Plugging this function into equation (17) enables to define E^* as an implicit function of the parameters. Let $E^*(.)$ denote the implicit function defined by equation (17). Plugging this function into equations (1') and (3'), we define the implicit functions $M^*(.)$ and $h^*(.)$, respectively.

Equation (18) enables us to clearly see that China's geopolitical effort is a function of all parameters of the model. It is important to stress that the relationship between China's geopolitical effort and the parameters is highly non-linear. As a result, the comparative statics are ambiguous for all exogenous variables of our model:

	r	α	β	δ	ρ	σ	ϑ
G^*	+/-	+/-	+/-	+/-	+/-	+/-	+/-
E^*	+/-	+/-	+/-	+/-	+/-	+/-	+/-
h^*	+/-	+/-	+/-	+/-	+/-	+/-	+/-
M^*	+/-	+/-	+/-	+/-	+/-	+/-	+/-

All endogenous variables are functions of time preference (impatience), r, on the depreciation rate of China's geopolitical effort, δ, on ROW's relative weight of consumption of electric goods at different times, ρ, on the coefficient of risk aversion, σ, on the importance of habits index ϑ, on the political benefit parameter of Chinese geopolitical influence on the control of critical minerals, α, and on ROW's exposure to China's geopolitical risk, β.

Although our theoretical model does not yield testable hypotheses between endogenous and exogenous variables, it yields two testable behavioral hypotheses, which we test in our empirical model. We do not directly observe China's geopolitical effort. The statistic Chinese geopolitical risk, however, is an increasing function of China's geopolitical effort. Hence, the testable hypotheses are:

1) There is a positive relationship between the amount of Chinese geopolitical risk and the amount consumed of electric goods.

2) There is a positive relationship between the amount of Chinese geopolitical risk and the quantity of critical minerals produced. We use the quantities of lithium and rare earths to capture the influence of geopolitical risk on critical minerals.

Since there is a positive relationship between the demanded quantity of electric goods and the supply of renewable energy needed to satisfy the demand, we also test the following hypothesis:

3) There is a positive relationship between Chinese geopolitical risk and the fraction of renewable energy to total energy produced (i.e., the energy transition rate).

3. Methodology and Data

We employ the Global Vector Autoregressive (GVAR) model. The GVAR combines individual VARX models into a system of open economies. It connects economies using proxies of economic integration, such as bilateral trade and financial flows. Equation 19 presents a VARX for region i at time t with k lags.

$$x_{it} = a_{i0} + a_{i1}t + \Phi_i x_{i,t-k} + \Lambda_{i0} x_{it}^{*} + \Lambda_{i1} x_{i,t-k}^{*} + \varepsilon_{it}. \tag{19}$$

On the left side, x_{it} is the vector of domestic variables for region i at time t. On the right side, a_{i0} is the constant, $a_{i1}t$ is the trend, $x_{i,t-k}$ is the vector of domestic variables lagged by k periods, x_{it}^{*} is the vector of foreign variables, $x_{i,t-k}^{*}$ is the vector of foreign variables lagged by k periods, and ε_{it} is the vector of idiosyncratic shocks.

Equation 20 shows how we construct foreign variables. We use the term w_{ij}, which corresponds to bilateral trade (or another proxy of economic integration) between regions i and j. In this context, the foreign variables vector, x_{it}^{*}, simulates the world economy and the vulnerability of region i to external shocks.

$$x_{it}^{*} = \sum_{j=0}^{N} w_{ij}\, x_{jt}. \tag{20}$$

Table 1 presents the variables, definitions, and sources. We construct the energy matrix (*energy*) through the ratio of renewable energy production to total energy production, where total energy production includes fossil fuel production (petroleum, natural gas, and coal). An increase in the energy ratio signifies an ongoing energy transition toward greener sources. The data were collected from the U.S. Energy Information Administration (EIA) via the International Portal.

We use the geopolitical risk index from Caldara and Iacoviello (2022). This index measures the frequency of geopolitical tensions in newspaper articles. An increase in the escalation of global tensions produces an increase in geopolitical risk (GPR).

We used the National Minerals Information Center of the United States Geological Survey (USGS) to collect the production data for lithium and rare earth in tons. The prices of lithium and rare earth were obtained from the Primary Commodity Prices dataset of the International Monetary Fund (IMF). Since these prices are in dollars, we employed the Consumer Price Index (CPI) of the U.S., sourced from the Organization for Economic Cooperation and Development (OECD) Economic Outlook, to deflate the prices of lithium and rare earth.

Table 1: Variables and sources

Variables	Definition	Sources
energy	Renewable energy production/total energy production	EIA
gpr	Geopolitical risk index	Caldara and Iacoviello (2022)
lithium	Lithium production (tons)	USGS/National Minerals Information Center
rare earth	Rare earth production (tons)	USGS/National Minerals Information Center
plit	Lithium real price	IMF/Primery Commodity Prices
prare	Rare earth real price	IMF/Primery Commodity Prices
chinese exports (china)	Index of Chinese exports (real) - Batteries and electric accumulators and parts thereof (778.1) and Rotating electric plant and parts thereof (716)	United Nation Comtrade, SITC
imp	Imports of Chinese goods (real) - Batteries and electric accumulators and parts thereof (778.1) and Rotating electric plant and parts thereof (716)	United Nation Comtrade, SITC
Oil	Crude Oil (petroleum), Price index, 2016 = 100, simple average of three spot prices; Dated Brent, West Texas Intermediate, and the Dubai Fateh. Deflated by U.S. CPI.	IMF/Primary Commodity prices

We represent Chinese exports of electrical goods to the world using sections 778.1 and 716 of The United Nations Commodity Trade Statistics Database (UN Comtrade, SITC). These goods incorporate relevant components and materials for the energy transition, such as batteries. We transformed this time series into an index (2007 = 100) and deflated it using the Chinese CPI. The imports from China adopt the same definition, incorporating relevant electrical components. Finally, we sourced oil prices from the Primary Commodity Prices of the IMF and deflated the oil price using the U.S. CPI.

We include oil prices because they are important in the world economy. Hamilton (1996), Kilian (2009), and Baumeister and Kilian (2016), for example, demonstrate that oil causes fluctuations in financial and productive sectors. We extend this understanding of oil prices affecting economic variables by connecting oil prices to energy matrices and critical minerals, as in Attílio et al. (2024).

Figure 1 illustrates the Chinese exports of electric goods to the global economy. The exports have shown a gradual increase over the years, with a notable acceleration since 2020.

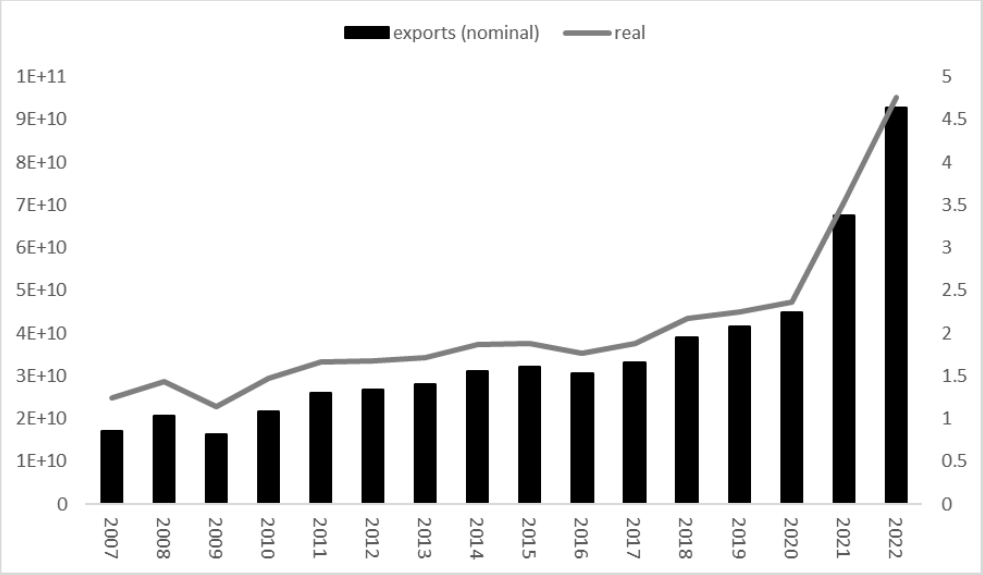

Figure 1: Chinese exports of electric goods

Note: The left axis displays values for the nominal time series, while the right axis represents values for the deflated time series.

Figure 2 displays the imports of electrical goods from China by Argentina (ARG), Australia (AUS), Brazil (BRA), Chile (CHL), India (IND), Malaysia (MAL), Portugal (PRT), Russia (RUS), Thailand (THA), the U.S., Vietnam (VIT), and Zimbabwe (ZIM). Similar to Figure 1, the imports showed a gradual increase over time, reaching a peak in the last few years.

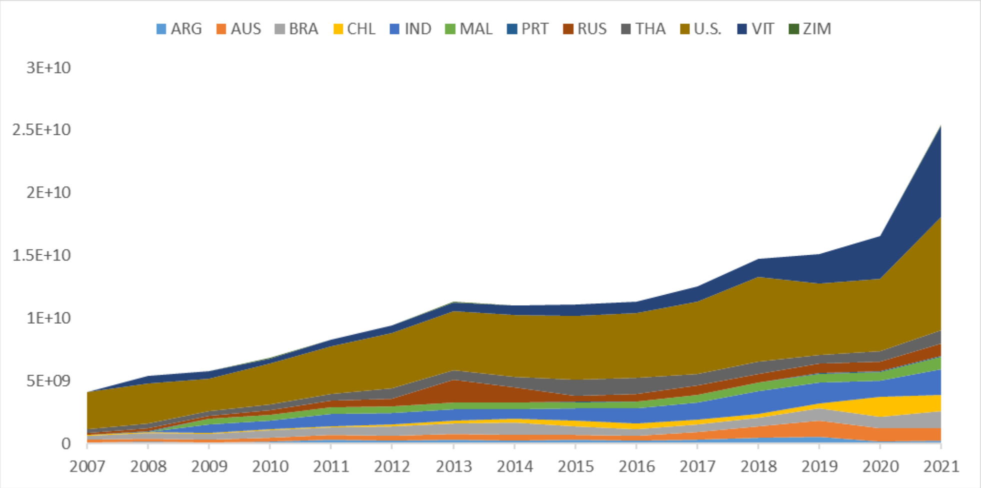

Figure 2: Imports of electric goods from China

Our investigation employs three models covering the period from July 2012 to December 2019. We initiate the analysis in 2012M7 due to the time series on lithium and rare earth prices. The analysis concludes in 2019M12 to align with the availability of time series on lithium and rare earth production. Recognizing the potential challenge of a limited number of observations, we applied the Denton procedure to convert the frequency of variables from annual to monthly, resulting in 90 observations for each variable.

Our sample consists of 12 economies: ARG, AUS, BRA, CHL, China (CHN), IND, MAL, PRT, RUS, THA, U.S., and ZIM. The selection of these economies was based on data availability regarding lithium and rare earth production. We conducted seasonal adjustments for lithium, rare earth, and oil prices. Additionally, we aggregated ARG, BRA, CHL, IND, MAL, PRT, RUS, THA, and ZIM to form a region labeled REST. This aggregation enables us to focus the analysis on Australia, a country with an almost monopolistic position in lithium production, China (which holds a dominant position in rare earth production), and the U.S. Furthermore, by reducing the number of regions, the estimation of the model is facilitated.

Equation 21 presents the vectors of the model 1:

$$x_{it} = (imp_{it}, gpr_{it}, energy_{it})$$

$$x^*_{it} = (energy^*_{it}, china^*_{it}, plit^*_{it}, prare^*_{it}, oil^*_{it}), \text{ for REST}$$

$$x_{it} = (gpr_{it,} energy_{it}, china_{it}, prare_{it})$$

$$x_{it}^{*} = (energy_{it}^{*}, plit_{it}^{*}, oil_{it}^{*}), \text{ for China}$$

$$x_{it} = (imp_{it}, gpr_{it,} energy_{it}, plit_{it})$$
$$x_{it}^{*} = (energy_{it}^{*}, china_{it}^{*}, prare_{it}^{*}, oil_{it}^{*}), \text{ for Australia}$$

$$x_{it} = (imp_{it}, gpr_{it}, energy_{it}, oil_{it})$$
$$x_{it}^{*} = (energy_{it}^{*}, china_{it}^{*}, plit_{it}^{*}, prare_{it}^{*}), \text{ for the U.S.} \qquad (21)$$

The terms *imp*, *gpr*, *energy*, *china*, *plit*, *prare*, and *oil* denote imports of electric goods from China, geopolitical risk, energy matrix, Chinese exports of electrical goods, lithium prices, rare earth prices, and oil prices.

We adapt the model to the characteristics of economies (Attílio et al., 2024). The variable *prare* is included as a domestic variable in the Chinese model because of its prominence in rare earth production (see Figure 4). Similarly, for Australia, we included *plit* as a domestic variable due to its almost monopolistic position in lithium production (see Figure 3). For the U.S., we followed studies that treat the oil price as a domestic variable in its model (Dees et al., 2007; Attílio and Mollick, 2024). We treated the energy matrix as a foreign variable in all models to capture the influence of the world energy matrix on the domestic equilibrium of economies. Finally, we treat Chinese exports (*china*) as a domestic variable in the Chinese model, a configuration we adopt in all models.

Model 2 focuses on the lithium market. Equation 22 shows the vectors of this model:

$$x_{it} = (lithium_{it}, gpr_{it}, energy_{it})$$
$$x_{it}^{*} = (energy_{it}^{*}, china_{it}^{*}, plit_{it}^{*}, oil_{it}^{*}), \text{ for REST}$$

$$x_{it} = (lithium_{it}, gpr_{it}, energy_{it}, china_{it})$$
$$x_{it}^{*} = (energy_{it}^{*}, plit_{it}^{*}, oil_{it}^{*}), \text{ for China}$$

$$x_{it} = (lithium_{it}, gpr_{it}, energy_{it}, plit_{it})$$
$$x_{it}^{*} = (energy_{it}^{*}, china_{it}^{*}, oil_{it}^{*}), \text{ for Australia}$$

$$x_{it} = (lithium_{it}, gpr_{it}, energy_{it}, oil_{it})$$

$$x_{it}^{*} = (energy_{it}^{*}, china_{it}^{*}, plit_{it}^{*}), \text{ for the U.S.} \qquad (22)$$

The principal difference between Models 1 and 2 is that we replace the variable imports (*imp*) for lithium production (*lithium*) and exclude the variable rare earth price (*prare*). Figure 3 shows the world's production of lithium, where Australia is the largest producer.

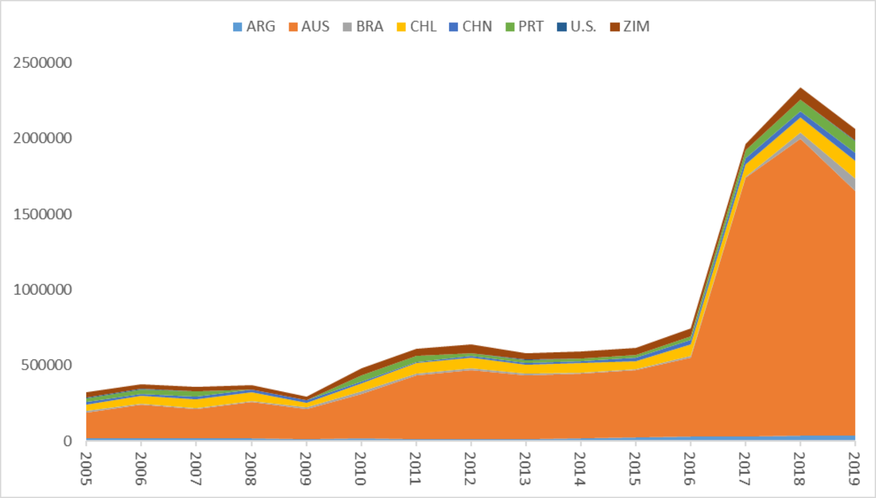

Figure 3: Lithium production

Model 3 analyzes the rare earth market. Equation 23 presents the vectors:

$$x_{it} = (rare_{it}, gpr_{it}, energy_{it})$$

$$x_{it}^{*} = (energy_{it}^{*}, china_{it}^{*}, prare_{it}^{*}, oil_{it}^{*}), \text{ for REST and Australia}$$

$$x_{it} = (rare_{it}, gpr_{it}, energy_{it}, china_{it}, prare_{it}^{*})$$

$$x_{it}^{*} = (energy_{it}^{*}, prare_{it}^{*}, oil_{it}^{*}), \text{ for China}$$

$$x_{it} = (rare_{it}, gpr_{it}, energy_{it}, oil_{it})$$

$$x_{it}^{*} = (energy_{it}^{*}, china_{it}^{*}, prare_{it}^{*}), \text{ for the U.S.} \qquad (23)$$

Regarding the differences between Models 2 and 3, we replace the variables lithium production (*lithium*) for rare earth production (*rare*) and lithium price (*plit*) for rare earth price (*prare*). The models for Australia and REST are similar. We include rare earth prices in the Chinese model as a domestic variable due to its almost monopolistic position (see Figure 4). In Figure 4, China is the major producer of rare earth, followed by the U.S. and Australia.

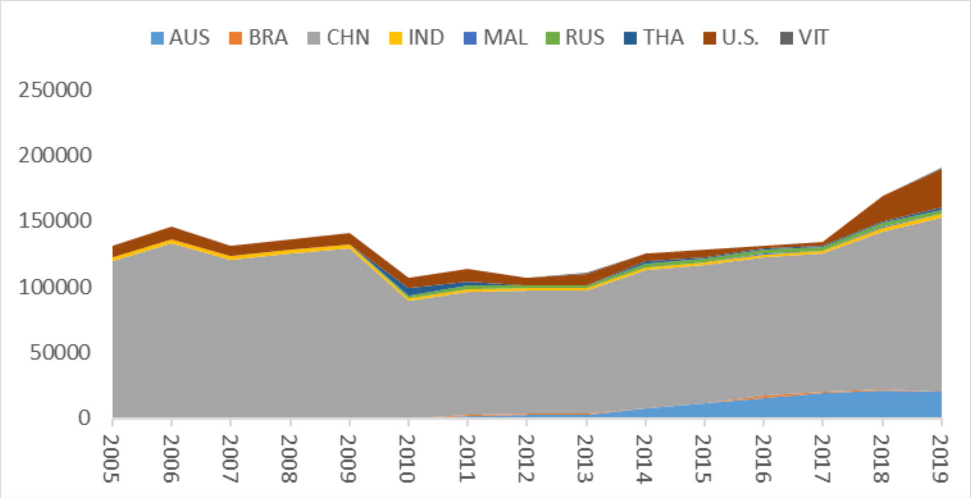

Figure 4: Rare earth production

Figure 5 displays the time series of lithium and rare earth real prices. Since 2016, lithium prices have risen to a higher level than in the initial months, while rare earth prices declined over time. Both prices surged after the Covid-19 pandemic: lithium prices reached 224 thousand dollars, and rare earth prices reached 5 thousand dollars in 2023M5. However, our model does not encompass these periods due to the considerations we made. One advantage of excluding the post-Covid-19 period is to avoid structural breaks in the time series. The linear correlation between lithium and rare earth prices from 2012M6 to 2019M12 is -0.46 (and 0.95 between 2012M6 and 2023M5).

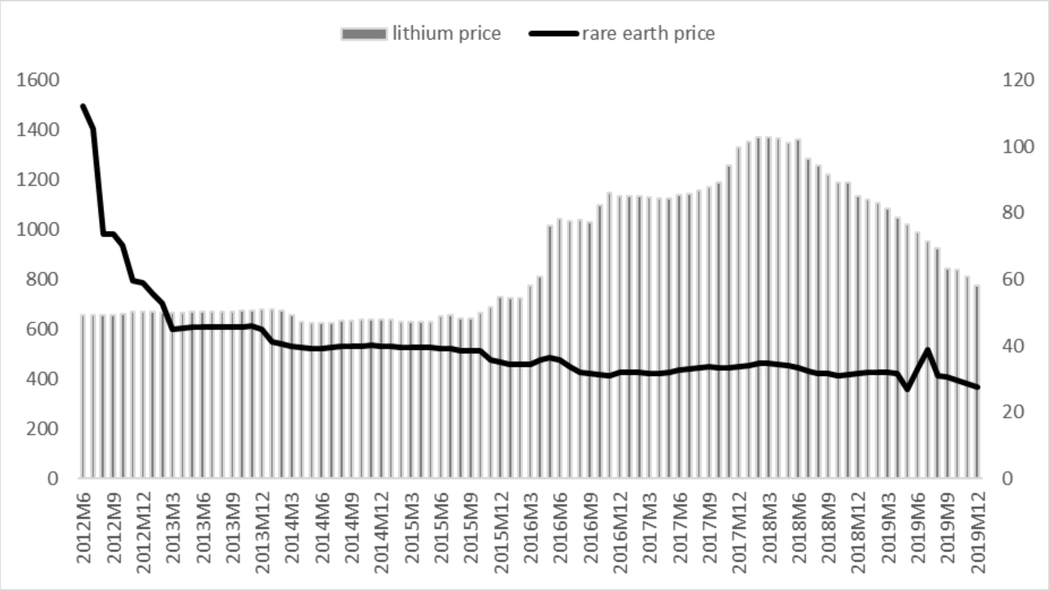

Figure 5: Lithium and Rare Earth Real Prices

We employ two tools to advance our analysis. The first is the Generalized Impulse Response Function (GIRF), which illustrates the response of all regions to a local shock. In our case, we analyze how the regions react to a shock in Chinese exports. Consequently, GIRFs suggest potential transmission channels of shocks and indicate spillover effects. However, GIRFs do not identify shocks. We use the Generalized Forecast Error Variance Decomposition (GFEVD) to help us comprehend the dissemination of Chinese shocks. Furthermore, we calculate confidence intervals at 90% using bootstrap in the GIRFs, where the shocks are one standard deviation.

The GFEVD shows the influence of domestic and external factors in explaining future values of a specific variable. Consequently, GFEVD quantitatively measures the spillover effects of the Chinese economy on domestic regions. We normalize each row of the GFEVD to a sum of 100%.

We adopt time-varying bilateral trade data between 2010 and 2022 from the Direction of Trade Statistics (DOTS) of the IMF to establish connections between economies, generate foreign variables, and solve the model. In the appendices, Table A presents the descriptive statistics of the variables[1].

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[1] All variables are in log differences, except for the energy matrix, which is in logarithmic form, and gpr, which is in level. We maintain this configuration in Models 2 and 3. However, Model 1 produces better-fitted estimates when using the log transformation for the *china* and *imp* variables. Consequently, we employed these variables in log form for Model 1 (results of Model 1 using all variables in log differences are available upon request).

In the appendices, Tables B-D present unit root tests for domestic, foreign, and global variables. Most variables exhibit stationarity in first differences but are nonstationary in levels. Table E displays the lags of the VARXs in the three models and the number of cointegrating relationships. Since Models 1-3 demonstrate nonstationarity in levels and cointegrating relationships, we adopt the GVAR in the error correction form (see Pesaran et al., 2004). Table F indicates that the weak-exogeneity test only rejects a few variables, supporting the configuration described in Equations 21-23.

4. Results

4.1 Habit Formation and Persistence

In this section, we explore how the exports of electrical goods from China affect the electrical imports of Australia, REST, and the U.S. Figure 6 presents the responses of imports to a positive shock in Chinese exports.

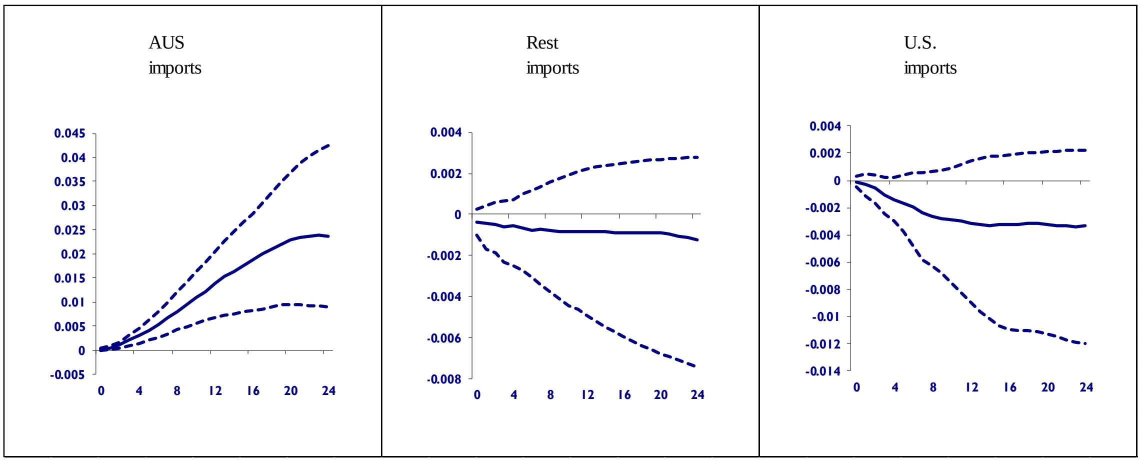

Figure 6: GIRF of a Chinese export shock and responses of imports

We find that Chinese exports impact the imports of Australia. The responses from REST and U.S. are statistically nonsignificant, as the estimates fall within the middle of the confidence intervals, encompassing positive and negative areas. Australian imports increased in response to the shock.

Another tool to capture the influence of China's electric exports is the GFEVD, which decomposes the values of imports (Table 2). Table 2 shows that, in the first period, Australian imports are explained as follows: 76% by itself, 0.05% by the energy matrix, and 12% by Australian GPR. These are the domestic factors affecting the imports of Australia. The second block in Table 2 measures the Chinese influence. Chinese GPR affects Australian imports by 0.3%, while Chinese exports impact imports by 7%. The third block shows the influence of international prices. Lithium prices affect imports by 1%, rare earth prices by 0.9%, and oil prices by 0.4%. These values change over time. Of particular interest is that, in the last period, Chinese geopolitical risk affects the consumption of electric goods in Australia by 6%, and Chinese exports affect Australian imports by 31%. Consequently, our model shows that China affects Australian consumption through geopolitical risk and exports of electric goods.

We captured the influence of Chinese GPR and exports on the Rest of the World and the U.S., although the values are lower than in the Australian case. Hence, these results validate the first hypothesis from the theoretical model, which affirms that Chinese geopolitical risk affects the consumption of electric goods. Furthermore, we also demonstrated that Chinese exports of electric goods provoke changes in the consumption patterns of other economies.

Table 2: GFEVD of imports

	Australia			China		Prices		
	imp	energy	Gpr	gpr	china	lithium	rare earth	oil
1	76.47	0.05	12.83	0.34	7.62	1.24	0.99	0.47
12	22.08	0.30	40.14	5.27	29.26	2.16	0.05	0.73
24	13.04	1.64	43.61	6.93	31.95	1.91	0.16	0.76

	Rest			China		Prices		
	imp	energy	Gpr	gpr	china	lithium	rare earth	oil
1	54.65	40.31	1.10	0.86	0.70	0.01	0.97	1.39
12	62.94	27.37	2.77	2.00	0.83	0.27	0.71	3.11
24	63.47	25.14	3.46	2.40	1.03	0.33	0.58	3.59

	U.S.			China		Prices		
	imp	energy	Gpr	gpr	china	lithium	rare earth	oil
1	52.89	42.53	0.98	0.22	1.21	0.17	1.69	0.31
12	29.06	24.28	10.24	2.89	3.89	0.33	1.98	27.32
24	22.14	20.17	9.28	2.50	3.53	0.57	1.81	39.99

Table 3: GFEVD of Lithium, Rare Earth, and Oil prices

		China		Prices		
		Gpr	China	lithium	rare earth	oil
Lithium prices	1	0.32	5.54	81.12	0.56	12.47
	12	0.49	5.43	60.15	0.65	33.28
	24	2.25	12.39	42.69	0.64	42.03

		China		Prices		
		Gpr	China	lithium	rare earth	oil
Rare Earth prices	1	11.63	4.57	1.78	78.82	3.20
	12	16.89	14.86	1.50	63.40	3.35
	24	21.78	21.00	1.35	51.12	4.75

		China		Prices		
		Gpr	China	lithium	rare earth	oil
Oil prices	1	1.37	1.08	0.96	0.18	96.41
	12	3.00	2.09	0.77	0.10	94.04
	24	1.58	1.05	0.78	0.26	96.33

Table 3 presents the GFEVD of lithium and rare earth prices and oil prices. In each panel, we display the variance decomposition of a specific price. For instance, the first part illustrates the influence of variables on the future values of lithium prices. In the last period, Chinese exports impact lithium prices at 12%, rare earth prices at 21%, and oil prices at 1%. Chinese geopolitical risk affects lithium prices by 2%, rare earth prices by 21%, and oil prices by 1%. Chinese exports and geopolitical risk have a higher influence on rare earth prices, reinforcing China's dominant position in this market. Since Table 2 demonstrates that these prices affect domestic imports, and now we observe that Chinese exports and geopolitical risk influence these prices, we can connect Tables 2 and 3 and argue that, indirectly, Chinese exports and GPR affect domestic imports by influencing the prices of critical minerals.

One possible rationale for these results is that economies import electric goods from China to advance and facilitate their transition to clean energy. However, as these transactions commence, there is a subsequent increase in dependence on Chinese electric goods. Given that the energy transition requires an escalating utilization of critical minerals and electric components (Islam et al., 2022; Zhu et al., 2022), economies procure these materials from China. In response, China strategically invests in these markets to enhance its global position and influence (Wang et al. 2024).

Regarding the influence of Chinese geopolitical risk, the estimates suggest that Chinese geopolitical efforts impact the markets for critical minerals, oil prices, and imports from other regions. Since the Chinese GPR is constructed based on China's actions in areas such as war threats and military buildup, the results indicate connections between these actions and changes in international consumption and prices. The geopolitical tensions caused by China lead to changes in other markets and countries, as other nations observe and respond to Chinese movements. In essence, we demonstrate that the Chinese geopolitical component affects other countries. This finding extends to other areas, such as energy transition and the production of critical minerals, as we demonstrate throughout the paper.

Dong et al. (2021) showed that the structure of the energy transition in China affects its energy poverty, and Wang et al. (2020) demonstrated that Chinese trade impacts pollution in other economies. Our results follow the same vein: Chinese exports of electrical goods provoke changes in other economies. Similar to Wang et al. (2020), we captured the spillover effects of Chinese exports. The subsequent sections explore other dimensions of the Chinese shock.

4.2 Lithium Model

We adopt the Lithium model to analyze the impact of Chinese exports of electrical goods on domestic lithium production, energy matrices, lithium price, and oil price. Figure 7 presents the Chinese shock and the responses of Australia, China, REST, and the U.S.

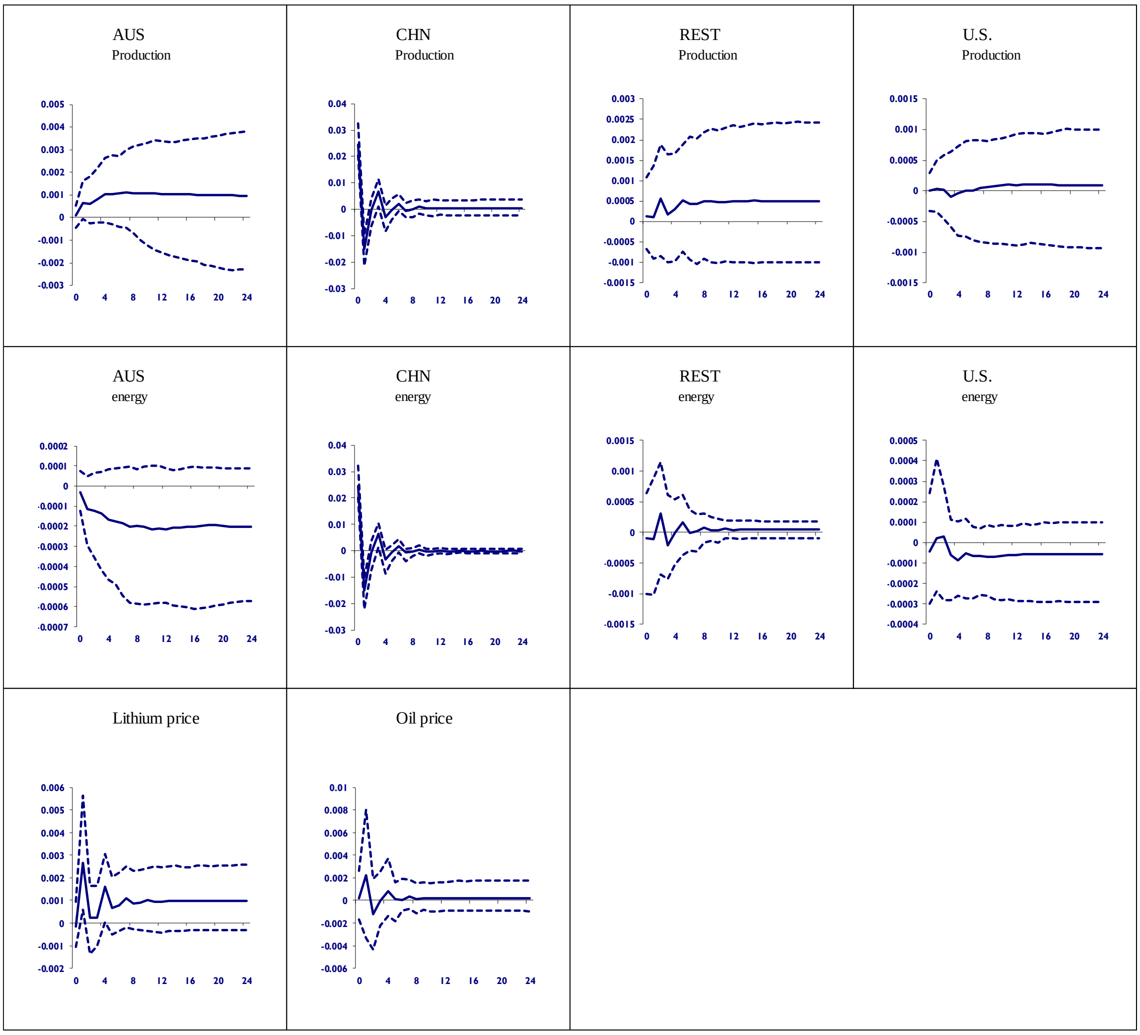

Figure 7: GIRF of a Chinese export shock (Lithium Model)

In China, there is a rapid increase and subsequent decrease in lithium production, but it loses statistical significance. In Australia, the REST and the U.S., the estimates fail to reach statistical significance. China exhibits a similar pattern in its energy matrix, with fluctuations at the beginning of the shock. While lithium prices increase, the oil price remains statistically nonsignificant.

Tables 4, 5, and 6 present the GFEVD of lithium production, energy matrices, and GPR, respectively. In each table, we analyze Chinese influence in four spheres: energy matrix (energy), lithium production (production), GPR, and exports of electrical goods (exports). Table 4 shows that Chinese geopolitical risk affects domestic lithium production by 2% in Australia, 0.8% in other regions, and 12% in the U.S. in the last period. The significant influence of Chinese geopolitical risk on the U.S. is a consistent finding across all tables. In Table 5, which presents the variance decomposition of the energy matrices, Chinese geopolitical risk affects all regions, particularly the U.S., by

18% in the last period. Table 6 presents the GFEVD of domestic geopolitical risk. Again, the estimates reflect the influence of Chinese geopolitical risk across all regions. Chinese exports of electric goods had a minor influence in all tables.

Table 4: GFEVD of Lithium production

	Australia			China				Prices	
	energy	production	gpr	energy	production	Gpr	china	lithium	oil
1	17.49	68.07	0.22	1.14	1.74	0.07	0.99	6.11	4.16
12	8.78	29.34	5.78	1.16	1.42	1.23	0.87	51.07	0.35
24	3.37	19.49	7.04	0.88	0.96	2.10	0.61	65.40	0.14

	China			China				Prices	
	energy	production	gpr	energy	production	Gpr	china	lithium	oil
1				33.14	33.00	0.12	32.88	0.63	0.23
12				30.37	30.58	6.01	30.18	1.11	1.75
24				27.01	27.60	15.94	26.82	1.08	1.55

	Rest			China				Prices	
	energy	production	gpr	energy	production	Gpr	china	lithium	oil
1	49.41	45.94	0.68	0.04	0.01	1.07	0.05	0.94	1.87
12	11.72	76.81	8.75	0.22	0.07	1.00	0.39	0.48	0.57
24	5.93	82.76	9.00	0.20	0.05	0.84	0.38	0.48	0.36

	U.S.			China				Prices	
	energy	production	gpr	energy	production	Gpr	china	lithium	oil
1	30.53	49.62	11.14	0.04	0.09	4.93	0.04	1.52	2.09
12	10.75	40.21	30.21	0.04	0.43	12.51	0.03	0.14	5.67
24	11.84	39.81	30.00	0.03	0.37	12.46	0.02	0.07	5.40

Table 5: GFEVD of energy matrices

	Australia			China				Prices	
	energy	production	gpr	energy	production	Gpr	china	lithium	oil
1	82.36	11.56	0.88	1.23	1.50	0.57	1.23	0.47	0.20
12	72.34	14.34	5.01	1.42	1.74	1.29	1.38	2.46	0.02
24	67.14	14.62	6.49	1.51	1.80	1.67	1.43	5.31	0.05

	China			China				Prices	
	energy	production	gpr	energy	production	Gpr	china	lithium	oil
1				33.11	32.99	0.17	32.84	0.60	0.29
12				32.30	32.16	0.46	32.11	1.15	1.82
24				32.10	31.98	1.05	31.92	1.14	1.81

	Rest			China				Prices	
	energy	production	gpr	energy	production	Gpr	china	lithium	oil
1	54.65	41.54	0.21	0.15	0.13	1.14	0.09	0.99	1.10
12	48.77	38.53	7.30	0.41	0.40	1.95	0.36	1.27	1.01
24	45.64	37.65	10.79	0.41	0.39	2.28	0.37	1.52	0.95

	U.S.			China				Prices	
	energy	production	gpr	energy	production	Gpr	china	lithium	oil
1	51.35	41.75	2.28	0.12	0.12	1.83	0.11	2.37	0.07
12	30.41	30.32	17.81	0.26	0.53	12.05	0.49	6.04	2.09
24	17.81	25.45	28.24	0.26	0.69	18.62	0.55	6.63	1.76

Table 6: GFEVD of geopolitical risk

	Australia			China				Prices	
	energy	production	gpr	energy	production	Gpr	china	lithium	oil
1	1.57	1.42	75.04	2.27	2.03	10.49	2.23	0.83	4.12
12	11.83	4.50	59.78	3.48	3.43	8.31	3.49	1.65	3.53
24	18.24	7.43	51.03	3.34	3.48	7.36	3.39	2.68	3.05

	China			China				Prices	
	energy	production	gpr	energy	production	Gpr	china	lithium	oil
1				0.30	0.54	98.22	0.35	0.18	0.41
12				0.96	1.86	92.34	0.89	3.29	0.67
24				1.17	3.20	88.70	0.86	5.34	0.74

	Rest			China				Prices	
	energy	production	gpr	energy	production	Gpr	china	lithium	oil
1	5.32	4.98	78.35	0.22	0.32	10.08	0.23	0.24	0.26
12	5.87	4.66	77.64	0.12	0.24	11.09	0.14	0.10	0.14
24	6.02	4.49	77.47	0.11	0.23	11.35	0.12	0.08	0.12

	U.S.			China				Prices	
	energy	production	gpr	energy	production	Gpr	china	lithium	oil
1	1.50	3.72	60.73	0.65	0.97	27.30	0.65	4.48	0.01
12	9.72	25.70	33.48	0.36	0.81	14.50	0.31	12.05	3.07
24	12.89	33.99	25.40	0.25	0.70	10.36	0.18	11.88	4.35

These results suggest that Chinese exports and GPR affect lithium production and energy transition. We can hypothesize that China uses lithium in the production of its electric goods, subsequently exporting these final products. Other economies, such as Australia, may use Chinese goods to complement their domestic supply of electric materials. These interactions can lead to changes in lithium prices (see figure 7). Shao and Jin (2020) and Qiao et al. (2021) demonstrated that changes in demand influence lithium supply. Our results reinforce this finding by indicating that Chinese exports induce changes in lithium production and prices.

These results imply the existence of potential geopolitical tensions involving energy transition and the production of critical minerals due to the increasing Chinese exports of electric goods. Islam et al. (2022) and Su et al. (2023) show that the demand for lithium can lead to changes in the energy transition process. Our estimates support this conclusion, demonstrating that China can influence the production and prices of lithium, thereby causing subsequent changes in energy transition.

These results validate hypotheses 2 and 3 from the theoretical model. We found that Chinese geopolitical risk affects the production of renewable energy and lithium. Tables 4 and 5 also highlight indirect channels of influence between Chinese GPR and renewable energy. For example, Table 4 shows that domestic energy matrices affect the domestic production of lithium, and Table 5 demonstrates that Chinese GPR affects the energy matrices of economies. By connecting Tables 4 and 5, we can argue that, indirectly, Chinese GPR affects the domestic production of lithium by causing changes in domestic energy matrices. Similarly, this reasoning could indicate indirect channels between Chinese GPR and domestic energy matrices.

4.3 Rare Earth Model

Figure 8 illustrates the impact of a Chinese electric goods export shock and the responses of the regions in the Rare Earth Model. The rare earth production in China increases, while the production in Australia and in the REST decrease (only in the first months in Australia).

The estimates indicate that the Chinese shock promotes energy transition in China and in the Rest. Rare earth prices increase, and oil prices show no significant response. Similar to Figure 7, which depicted the rise in lithium prices, Figure 8 also illustrates an increase in rare earth prices. Consequently, the Chinese exports of electric goods cause changes in the prices of critical minerals, especially rare earth prices, reflecting the dominant position of China in this critical mineral.

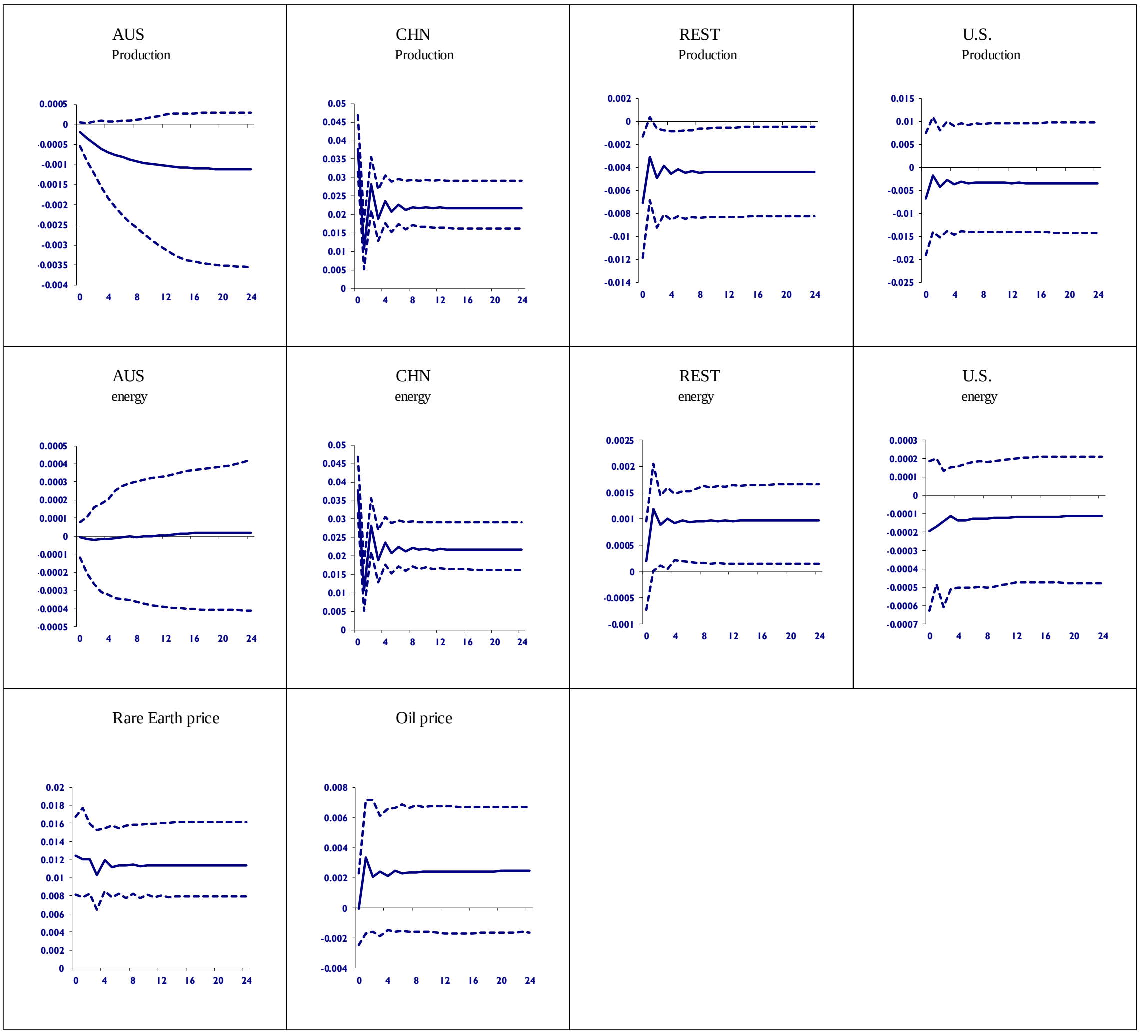

Figure 8: GIRF of a Chinese export shock (Rare Earth Model)

Following the previous section, Tables 7, 8, and 9 present the GFEVD of rare earth production, energy matrices, and GPR. We are particularly interested in the Chinese influence on other economies. Table 7 shows that Chinese geopolitical risk has a low influence on all economies. A key difference from the lithium model is that in the Rest, the estimates captured a significant influence of China on rare earth production through its energy matrix (3.3%), rare earth production (3.3%), and exports (3.3%) in the last period. Together, these variables explain around 10% of the fluctuation in rare earth production in the Rest.

Table 7: GFEVD of Rare Earth production

	Australia			China				Prices	
	energy	production	gpr	energy	production	gpr	china	rare earth	oil
1	1.14	93.20	0.53	1.43	1.37	0.02	1.50	0.27	0.53
12	1.18	90.49	2.72	1.34	1.29	0.13	1.43	0.29	1.14
24	1.05	90.08	3.14	1.33	1.28	0.17	1.42	0.29	1.22

	China			China				Prices	
	energy	production	gpr	energy	production	gpr	china	rare earth	oil
1				28.56	28.55	0.41	28.52	13.50	0.45
12				27.33	27.32	0.10	27.33	17.36	0.55
24				27.13	27.12	0.06	27.13	17.99	0.58

	Rest			China				Prices	
	energy	production	gpr	energy	production	gpr	china	rare earth	oil
1	9.27	75.95	0.11	4.30	4.30	0.49	4.30	0.14	1.15
12	15.87	71.09	0.02	3.47	3.48	0.91	3.46	0.08	1.61
24	16.73	70.50	0.01	3.33	3.34	1.06	3.33	0.07	1.63

	U.S.			China				Prices	
	energy	production	gpr	energy	production	gpr	china	rare earth	oil
1	10.86	83.17	0.31	0.32	0.32	1.33	0.32	0.49	2.87
12	13.80	82.07	0.05	0.25	0.25	0.87	0.24	0.56	1.93
24	14.00	81.98	0.02	0.24	0.24	0.86	0.23	0.56	1.86

Table 8: GFEVD of energy matrices

	Australia			China				Prices	
	energy	production	Gpr	energy	production	gpr	china	rare earth	oil
1	91.14	1.41	2.80	0.07	0.08	4.07	0.10	0.01	0.31
12	80.44	6.01	8.33	0.01	0.01	5.13	0.02	0.03	0.01
24	78.01	9.06	7.94	0.01	0.01	4.93	0.01	0.02	0.01

	China			China				Prices	
	energy	production	Gpr	energy	production	gpr	china	rare earth	oil
1				28.56	28.56	0.41	28.53	13.50	0.44
12				27.37	27.35	0.11	27.35	17.30	0.53
24				27.18	27.15	0.06	27.16	17.90	0.55

	Rest			China				Prices	
	energy	production	Gpr	energy	production	gpr	china	rare earth	oil
1	57.41	13.93	6.39	2.82	2.81	1.48	2.76	0.63	11.77
12	19.67	30.35	14.49	3.73	3.72	2.77	3.64	0.21	21.41
24	14.42	32.70	15.55	3.92	3.90	3.04	3.82	0.15	22.50

	U.S.			China				Prices	
	energy	production	Gpr	energy	production	gpr	china	rare earth	oil
1	69.24	10.74	5.93	1.00	1.01	2.52	1.04	1.48	7.05
12	48.04	12.39	14.86	0.87	0.89	5.21	0.95	1.05	15.74
24	46.64	12.58	15.72	0.78	0.81	5.08	0.88	1.03	16.48

Table 9: GFEVD of GPR

	Australia			China				Prices	
	energy	production	Gpr	energy	production	gpr	china	rare earth	oil
1	4.41	0.45	71.20	2.48	2.47	8.56	2.41	0.46	7.56
12	14.40	3.08	35.16	3.07	3.06	8.18	3.00	1.25	28.80
24	16.31	5.11	26.15	3.13	3.12	8.08	3.05	1.39	33.65

	China			China				Prices	
	energy	production	Gpr	energy	production	gpr	china	rare earth	oil
1				3.48	3.47	87.90	3.39	1.72	0.03
12				3.95	3.95	86.94	3.88	1.27	0.01
24				4.00	4.00	86.80	3.93	1.26	0.01

	Rest			China				Prices	
	energy	production	Gpr	energy	production	gpr	china	rare earth	oil
1	1.77	0.33	78.09	1.07	1.07	16.53	1.06	0.10	0.00
12	1.71	0.38	78.96	0.85	0.85	16.31	0.84	0.10	0.01
24	1.70	0.39	79.05	0.83	0.83	16.29	0.81	0.10	0.01

	U.S.			China				Prices	
	energy	production	Gpr	energy	production	gpr	china	rare earth	oil
1	6.71	0.53	62.80	1.40	1.40	22.83	1.33	0.40	2.59
12	16.06	0.70	52.19	1.50	1.49	19.89	1.38	0.52	6.27
24	16.81	0.72	51.05	1.54	1.53	19.87	1.41	0.52	6.55

In Table 8, Chinese geopolitical risk affects Australia, the Rest, and the U.S. by approximately 3-5%, reinforcing the link between Chinese geopolitical risk and changes in domestic energy matrices. Finally, Table 9 shows a significant influence of Chinese geopolitical risk on the Rest and the U.S., with values in the range of 16-19%. Compared to the lithium model, Chinese geopolitical risk plays a more prominent role in affecting the Rest in the rare earth model, perhaps illustrating China's position in the rare earth market.

Regarding the U.S., Table 8 shows a high influence of oil prices on the U.S. energy matrix. Attílio et al. (2024) argued that the U.S. adopted the production of fossil fuels as a strategic move to maintain its international position, while China focused on electric goods. This result suggests this dynamic. Furthermore, in Tables 4-9, critical mineral prices show a significant influence on major producers. For example, in Table 4, Australian lithium production is primarily explained by lithium prices in the last period (65%). Chinese rare earth production is explained by rare earth prices by 18% in the last period (Table 7). Besides these results, these prices also affect energy matrices and geopolitical risk, although to a lesser extent.

Wubbeke (2013), Wang et al. (2017), Shen et al. (2020), and Hau et al. (2022) demonstrated the influence of rare earth production and prices on Chinese pollution, policies, energy matrices, and trade uncertainty. Our results confirm the impact of rare earth on economic and non-economic variables. The findings of this section indicate that Chinese exports of electrical goods affect the rare earth market, leading to subsequent changes in energy matrices. Chen et al. (2020) argued for an interdependence between rare earth, energy markets, and oil prices. Our results reinforce the existence of these linkages, extending this conclusion to other regions (spillover effects). Our results also support the studies by Brown and Eggert (2018) and Gielen and Lyons (2022), which explored the potential consequences of rare earth elements in China and for the global energy transition.

Similar to the lithium model, the present model confirmed the hypotheses raised in the theoretical model. Hypotheses 2 and 3 were validated: the empirical model showed that Chinese geopolitical risk affects renewable energy and rare earth production.

5. Conclusion

This paper makes two main contributions to the literature. First, it provides a differential game to capture China's dominant position and its strategies in the upstream and downstream electricity supply chain. Second, we estimate important global impacts caused by China's actions, both economic and geopolitical ones. For example, our paper considers the impacts caused by China's significant control of exports of electric goods and China's geopolitical risk on domestic energy transitions, critical mineral production and prices, and oil prices. The theoretical model yields testable hypotheses, which are verified in the empirical model.

We contribute to the literature by establishing connections between Chinese exports and geopolitical risk, critical minerals, and energy transition within a system of open economies. In doing so, we capture the spillover effects of the Chinese economy on the international energy transition. In terms of critical minerals, we focus on impacts on lithium and rare earth prices. We analyze lithium and rare earth production; however, future work should also consider other critical minerals, such as graphite, cobalt, and nickel. Our findings demonstrate that there is a greater Chinese influence in the rare earth market than in the lithium market. As explorations of other critical minerals evolve around the world, China's dominant position in the upstream supply chain will tend to reduce. The diversification of the upstream supply chain is a process that the world should welcome and provide significant policy incentives. As the White Paper discussed in the introduction proposes, there should also be policies targeted to increase the critical minerals' utilization efficiency and recycling.

In addition to the economic implications, our results suggest the potential for geopolitical tensions among Australia, China, and the U.S. Given the significance of critical minerals, these economies, and others, may formulate national policies to ensure incentives for increased exploration of these minerals. As history has shown with oil conflicts (Yergin, 2011), armed disputes can emerge from differences among nations. Therefore, our paper serves as a cautionary call regarding the potential for geopolitical conflicts.

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Appendices

Table A: Descriptive Statistics

imp	Mean	Median	Maximum	Minimum	Std. dev.
Australia	0.196	0.135	0.544	0.020	0.166
China					
REST	0.156	0.158	0.247	0.077	0.048
U.S.	0.084	0.072	0.180	0.023	0.042

energy	Mean	Median	Maximum	Minimum	Std. dev.
Australia	0.001	0.002	0.009	-0.009	0.004
China	0.003	0.005	0.093	-0.076	0.035
REST	0.001	0.002	0.012	-0.011	0.005
U.S.	0.000	0.000	0.011	-0.006	0.003

gpr	Mean	Median	Maximum	Minimum	Std. dev.
Australia	0.094	0.084	0.251	0.028	0.052
China	0.587	0.499	1.521	0.222	0.298
REST	0.257	0.252	0.599	0.104	0.091
U.S.	2.231	2.163	3.557	1.433	0.501

lithium production	Mean	Median	Maximum	Minimum	Std. dev.
Australia	0.006	-0.001	0.068	-0.038	0.022
China	0.010	0.009	0.106	-0.087	0.037
REST	0.009	0.005	0.062	-0.023	0.017
U.S.	-0.001	-0.002	0.030	-0.023	0.011

rare earth production	Mean	Median	Maximum	Minimum	Std. dev.
Australia	0.009	0.007	0.052	-0.029	0.016
China	0.002	0.004	0.089	-0.078	0.035
REST	0.002	0.002	0.139	-0.090	0.021
U.S.	0.008	0.004	0.465	-0.496	0.105

Global variables	Mean	Median	Maximum	Minimum	Std. dev.
china	0.108	0.096	0.202	0.025	0.049
lithium price	0.001	0.000	0.096	-0.033	0.014
rare earth price	-0.007	-0.002	0.084	-0.158	0.027
oil price	-0.002	0.003	0.084	-0.106	0.033

Table B: Unit root test (Weighted Symmetric) for Domestic Variables at 5% of Statistical Significance

Domestic Variables	Critical Value	AUS	CHN	REST	U.S.
imp (with trend)	-3.24	-1.94		-3.56	-3.39
imp (no trend)	-2.55	-0.95		-3.74	-2.75
Dimp	-2.55	-2.49		-1.49	-1.86
energy (with trend)	-3.24	-4.07	-7.23	-3.01	-2.59
energy (no trend)	-2.55	-4.09	-7.16	-2.99	-2.43
Denergy	-2.55	-2.49	-8.76	-9.79	-10.86
lithium production (with trend)	-3.24	-3.91	-3.78	-3.35	-3.40
lithium production (no trend)	-2.55	-3.92	-3.79	-3.10	-2.97
Dlithium production	-2.55	-3.92	-7.44	-3.62	-3.56
rare earth production (with trend)	-3.24	-3.54	-6.86	-4.22	-3.98
rare earth production (no trend)	-2.55	-3.28	-6.80	-4.24	-3.95
Drare earth production	-2.55	-3.83	-8.68	-9.36	-4.31
gpr (with trend)	-3.24	-4.91	-4.63	-4.94	-4.96
gpr (no trend)	-2.55	-4.35	-2.05	-2.87	-4.23
Dgpr	-2.55	-4.92	-8.94	-9.53	-8.41

Table C: Unit root test (Weighted Symmetric) for Foreign Variables at 5% of Statistical Significance

Foreign Variables	Critical Value	AUS	CHN	REST	U.S.
imp* (with trend)	-3.24	-2.94	-3.01	-3.41	-3.82
imp* (no trend)	-2.55	-2.87	-1.79	-2.28	-3.78
Dimp*	-2.55	-2.13	-1.98	-1.76	-1.41
energy* (with trend)	-3.24	-11.03	-2.66	-6.64	-7.00
energy* (no trend)	-2.55	-11.02	-2.60	-6.53	-6.93
Denergy*	-2.55	-8.11	-9.54	-8.53	-8.42
lithium production* (with trend)	-3.24	-3.92	-2.33	-3.51	-3.76
lithium production* (no trend)	-2.55	-3.95	-2.35	-3.48	-3.76
Dlithium production*	-2.55	-7.92	-5.75	-8.14	-7.33
rare earth production* (with trend)	-3.24	-3.43	-3.75	-3.49	-7.79
rare earth production* (no trend)	-2.55	-3.41	-3.75	-3.49	-7.83
Drare earth production*	-2.55	-4.94	-4.45	-9.05	-8.08
gpr* (with trend)	-3.24	-4.99	-3.27	-5.15	-4.79
gpr* (no trend)	-2.55	-3.46	-2.03	-3.76	-2.02
Dgpr*	-2.55	-8.68	-8.60	-8.67	-9.07

Table D: Unit root test (Weighted Symmetric) for Global Variables at 5% of Statistical Significance

Global Variables	Critical Value	Statistic
china (with trend)	-3.24	-6.79
china (no trend)	-2.55	-6.81
Dchina	-2.55	-8.66
plit (with trend)	-3.24	-1.95
plit (no trend)	-2.55	-1.75
Dplit	-2.55	-9.76
prare (with trend)	-3.24	-2.97
prare (no trend)	-2.55	-1.08
Dprare	-2.55	-8.74
oil (with trend)	-3.24	-5.98
oil (no trend)	-2.55	-6.01
Doil	-2.55	-7.55

Table E: VARX order and number of cointegrating relationships

MODEL 1 (imports)			
	VARX (p,q)		cointegrating relationships
	p	q	
Australia	2	1	2
China	2	1	1
REST	2	1	1
U.S.	2	1	2

MODEL 2 (lithium)			
	VARX (p,q)		cointegrating relationships
	p	q	
Australia	2	1	2
China	2	2	2
REST	2	1	1
U.S.	2	1	3

MODEL 3 (rare earth)			
	VARX (p,q)		cointegrating relationships
	p	q	
Australia	2	1	1
China	2	1	1
REST	1	1	1
U.S.	1	1	1

Table F: Weak Exogeneity Test at 5% of Statistical Significance

	Critical values	MODEL 1				
		energy*	china*	plit*	prare*	oil*
Australia	3.13	2.19	2.24		0.10	0.02
China	3.96	4.70		0.15		0.06
REST	3.98	0.05	0.06	1.09	0.67	0.92
U.S.	3.13	0.19	0.17	0.28	0.31	

	Critical values	MODEL 2				
		energy*	china*	plit*	prare*	oil*
Australia	3.12	0.77	0.78			0.96
China	3.12	1.08		0.17		0.26
REST	3.96	0.04	0.03	0.15		0.44
U.S.	2.73	0.29	0.24	0.43		

	Critical values	MODEL 3				
		energy*	china*	plit*	prare*	oil*
Australia	3.97	0.69	0.68		1.25	1.30
China	3.96	3.39				0.76
REST	3.97	0.03	0.05		1.78	0.24
U.S.	3.97	0.12	0.14		0.00	

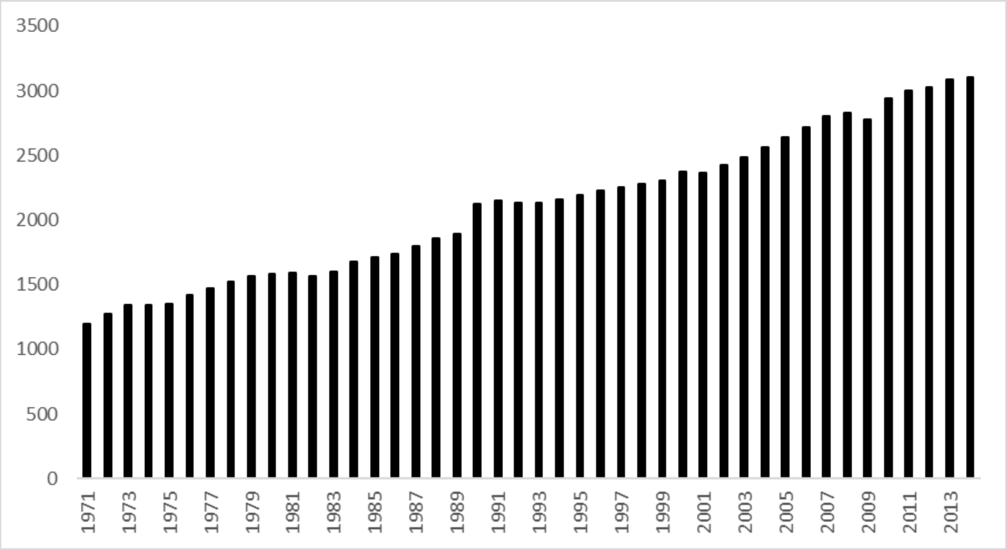

Figure A: Electric power consumption (kWh per capita).

Source: World Bank/WDI

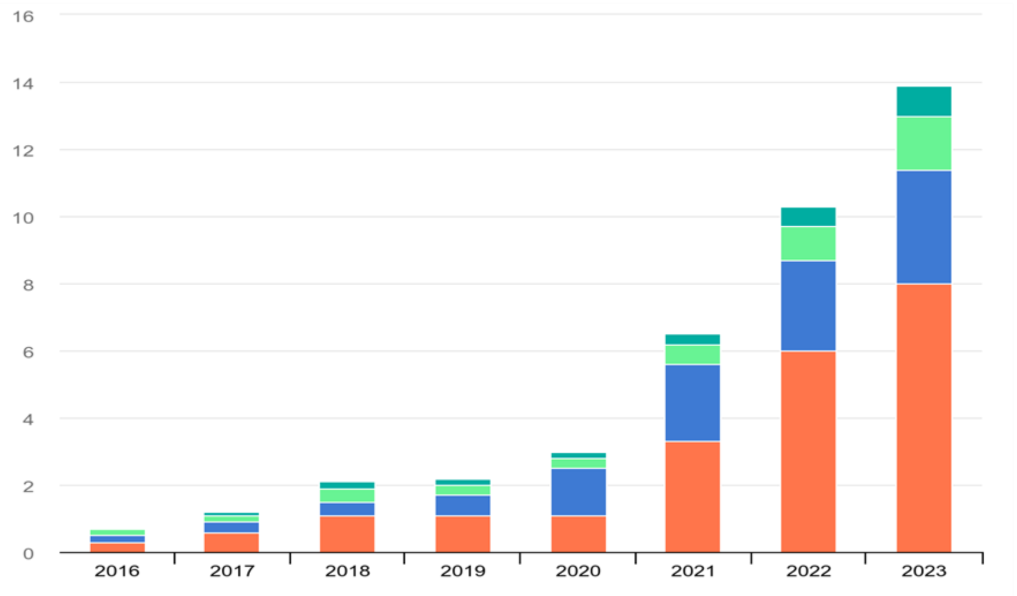

Figure B: Electric car sales, 2016-2023

Source: International Energy Agency (IEA)

Note: Orange represents China, blue represents Europe, light green represents the U.S., and dark green represents others.