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"ANALYSIS: LITHIUM – MEASURING THE INCENTIVE TO COLLUDE"

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Analysis: Lithium – Measuring the Incentive to Collude

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This study analyzes the potential for collusion within the Lithium Carbonate Equivalent (LCE) market from 2013 to 2021, focusing on Argentina, Chile, and Australia. Lithium, a cornerstone of the renewable energy transition, is produced under oligopolistic market conditions. Using a Cournot framework, this research evaluates deviations from Nash equilibrium production to assess profitability under collusive agreements. The study incorporates price, production volume, and cost data while adapting computational methodologies from Igami and Sugaya's vitamin cartel model. Findings indicate that Chile and Argentina act as price takers, lacking economic leverage for profitable collusion due to Australia's rapid production expansion post-2017. The analysis reveals structural barriers to collusion, emphasizing the impact of production cost asymmetries and market competitiveness. Limitations include the reliance on fixed cost assumptions and the absence of mine-specific data, with recommendations for future research addressing these gaps through dynamic demand modeling and the inclusion of production elasticity metrics. This paper contributes to the understanding of collusive dynamics in resource markets, particularly in the context of the growing demand for critical minerals in renewable energy applications.

Introduction

This study investigates the financial viability of collusive behavior in the Lithium Carbonate Equivalent (LCE) market from 2013 to 2021, with a focus on the dominant producing nations of Argentina, Chile, and Australia. Lithium's central role in the renewable energy transition and the oligopolistic structure of its production market render it a critical subject for economic analysis. Employing a Cournot framework, this research aims to quantify the potential profitability of collusion among producers by examining deviations from Nash equilibrium levels of production. The results reveal minimal incentive for collusion, positioning Chile and Argentina as price takers within the market.

Key variables for this analysis include LCE prices, production volumes, and cost structures. Given data constraints, production costs were assumed constant and uniform across Chile and Argentina. The study leverages modified Python scripts and MATLAB algorithms adapted from Igami and Sugaya's foundational work on the vitamin cartel (Igami and Sugaya, 2021), enabling the generation of equilibrium profit functions specific to the lithium market. These computational tools allowed for robust modeling of market dynamics and profit-maximizing behaviors.

Methodology

The Nash equilibrium quantities of production for the countries are calculated in MATLAB and run with Python code (Igami and Sugaya, 2021). The analysis incorporates the following variables:

- Price of Lithium Carbonate Equivalent (USGS, 2022).
- Lithium Carbonate Equivalent production quantity for each country (Benchmark, 2022).
- Chilean fixed average cost of production (Benchmark, 2022).
- Population data of each country (World Bank, 2022).

The Cournot cartel analysis requires a defined profit function in a market where each firm strategically chooses its quantity of output. In the Cournot equation, profits are expressed as:

$$\pi_i(q_1, \ldots, q_n) = q_i P\left(\sum_{j=1}^{n} q_j\right) - C_i(q_i).$$

(Cramton, 2013)

where:

- Single good produced by *n* countries.
- Cost to country *i* for producing *qi* units (Benchmark, 2022).
- *Ci(qi)* where *Ci* is positive.
- *Q* is total production (Benchmark, 2022).
- *P* is market price (USGS, 2022).

Each game played has its own Nash equilibrium payoff function determined by the sale price in a competitive market and the cost of production. Each country has its profit function and most profitable quantity of production for each year of the analysis. This analysis calculates many best response functions and compares them to the price of lithium and the quantity produced (USGS, 2022; Benchmark, 2022).

The equilibrium quantity to produce is determined as follows:

$$(q_1^*, q_2^*) = ((\alpha - c)/3, (\alpha - c)/3)$$

(Cramton, 2013)

where:

- At equilibrium, each country's profit is $(\alpha - c)^2 / 9$ (Cramton, 2013).
- Total production, $2(\alpha - c)/3$, is between monopoly output and competitive output $(\alpha - c)$ (Cramton, 2013).

The Nash equilibrium quantity seeks to maximize output while the cartel equilibrium seeks to maximize the profit of each firm by choosing the quantity of output that maximizes the difference between total revenues *(pi(qi)*qi)* and total costs *Ci(qi)*, considering strategic interactions with other firms in the market. (Chan, 2015; Cramton, 2013). The Nash equilibrium also represents the stable outcome of strategic competition between firms, in perfect competition. The Cournot model can be extended to include additional factors such as demand elasticity, production capacity, and cartel agreements for a more complete analysis of oligopoly markets (Chan, 2015). For this analysis, those extra variables were not a significant part of the consideration in determining a Nash equilibrium quantity.

The Cournot framework was selected as the analytical model due to the homogeneous nature of LCE and its competitive market characteristics. This approach assumes that producers strategically choose production quantities to maximize profits, taking into account the output decisions of competitors. The following variables were integral to the analysis:

- LCE pricing and production data sourced from USGS (2022) and Benchmark (2022).
- Fixed production costs derived from Chile's average (Benchmark, 2022).

Profit maximization was achieved by solving for Nash equilibrium outputs for Argentina and Chile under competitive production conditions. The analysis incorporates theoretical insights from Robert Porter's framework on cartel stability, which employs weekly time series data on the Joint Executive Committee railroad cartel from 1880 to 1886 (Porter, 1983). Specifically, Porter's concepts of dynamic stability and reversionary strategies informed the interpretation of potential collusive incentives.

Australia's increasing production capacity posed a significant variable in the analysis, influencing the profitability of collusive strategies for other producers. The study's assumptions of perfect competition and fixed production costs simplified the computational modeling but also introduced limitations that warrant consideration in future research.

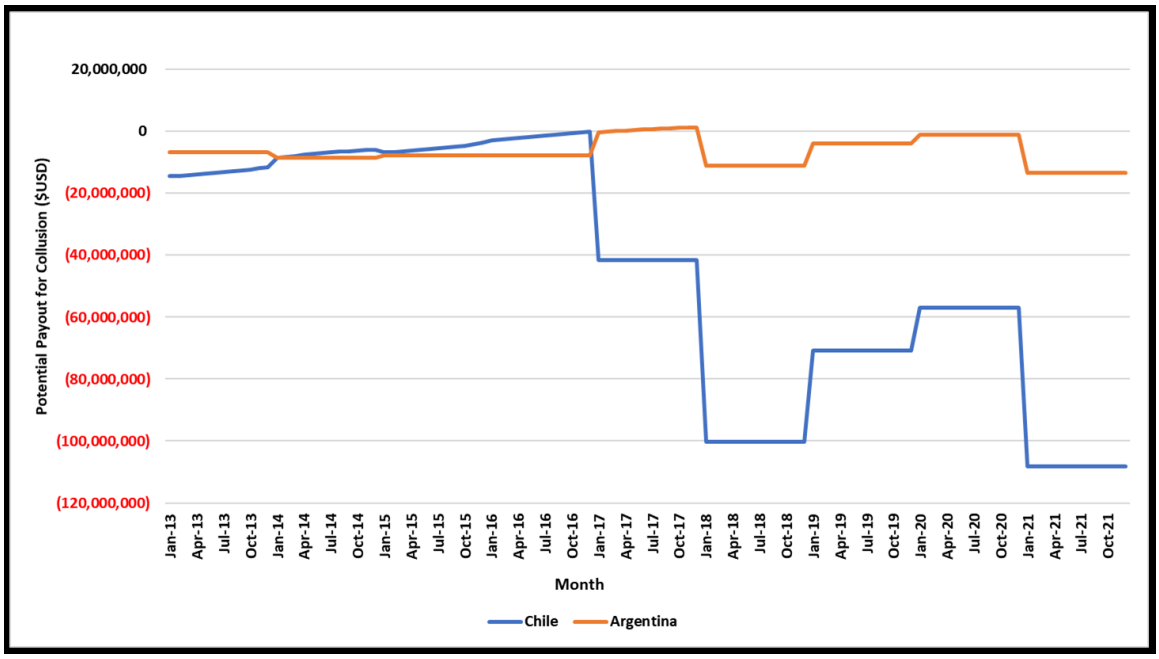
Results

Graphical findings illustrate the absence of financial incentives for collusion between Chile and Argentina against Australia from 2013 to 2021. See Figure 1 on the next page. Notably, Australia's substantial production expansion post-2017 exacerbated the negative profitability of collusive strategies, particularly for Chile. By 2017, Australian production growth had effectively eliminated any potential gains from collusion, further entrenching Chile's and Argentina's roles as price takers in the global LCE market.

The analysis highlights the impact of Australia's production dynamics on the broader market. Chile and Argentina, operating under constrained production capacities and limited cost advantages, lacked the economic leverage required to influence market prices through collusion. Additionally, production in Chile and Argentina is primarily from brine deposits, which have a lagged time to market, while production in Australia is from hard rock deposits, which enters the market quickly. These findings underscore the structural barriers to effective collusion in the lithium market, even among geographically proximate producers with shared economic interests.

The Nash equilibrium quantities of production, calculated through iterative algorithms, were cross-validated using Porter's dynamic cartel modeling techniques. This approach demonstrated that deviations from competitive production levels to collusive agreements were infeasible given Australia's aggressive market entry and expansion. Furthermore, the profit functions generated revealed diminishing returns to collusion under real-world market pressures, further reducing incentives for coordinated production cuts.

Figure 1
Monetary Incentive to Collude (2013-2021)



Interpretation

While the study provides valuable insights into the economic dynamics of the LCE market, its conclusions are subject to several limitations. Chief among these is the reliance on incomplete production cost data and the extrapolation of fixed cost assumptions across multiple years. The absence of granular, mine-specific production cost data limits the precision of the findings and introduces potential biases in profit calculations.

The structural differences between brine-based and hard-rock LCE production further complicate market modeling. Brine extraction typically benefits from lower marginal costs but is slower to scale in response to demand shocks, whereas hard-rock mining offers greater responsiveness at the expense of higher production costs. Future research should incorporate elasticity measures to differentiate these production methods and their respective impacts on collusive behavior.

Future research could address these limitations through the following avenues:

- Incorporation of comprehensive, mine-specific production cost data to enhance model accuracy.
- Development of a three-player Cournot model that explicitly includes Australia as an independent strategic actor, offering a more nuanced understanding of market interactions.
- Integration of advanced, dynamic demand models tailored to the unique characteristics of the lithium market, accounting for temporal variations in demand elasticity and external market shocks.

- Accounting for the differing elasticity of supply between brine-based LCE production and hard-rock LCE production, as these variations significantly affect market dynamics, cost structures, and time-to-market.

By addressing these dimensions, future analyses can provide a more comprehensive understanding of the underlying factors influencing collusion incentives in the lithium market.

Conclusion

This analysis demonstrates that there were minimal incentives for collusion in the LCE market during the 2013-2021 period. Chile and Argentina function predominantly as price takers, while Australia's expanding production capacity reinforces the competitive dynamics of the market. The findings align with broader economic theories of oligopolistic competition, wherein structural asymmetries among producers inhibit effective collusion.

Enhanced datasets and refined computational models will be essential for advancing the understanding of lithium market dynamics. Future studies could explore the interplay between production technologies, geopolitical factors, and market structures to provide a more comprehensive assessment of collusion incentives in the LCE sector. Additionally, the integration of elasticity parameters and dynamic cost modeling could yield more granular insights into the strategic behaviors of market participants, particularly in the context of the evolving renewable energy landscape.

Endnotes

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Author Biography

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Scott Pollan is a commodity economist and author with deep expertise in derivatives trading, risk management, quantitative modeling, and market analysis. His professional experience spans a wide range of sectors, including commodities, foreign exchange, critical materials, mining, and recycling.

Mr. Pollan has held senior roles as a commodity trader and risk manager, specializing in automated precious metals risk management and market-making algorithms. His company, Emergency Material Services, has also provided consultancy services for high-net-worth individuals (HNWI) and ultra-high-net-worth individuals (UHNWI) in the metals and recycling industries, delivering bespoke economic analysis and risk management strategies. His career includes significant contributions to the mining and critical materials sectors, where he has conducted research on resource scarcity, developed mathematical models for mineral cartel formation, and advised on the economic impact of large-scale metals industry projects.

Mr. Pollan's experience includes positions (1) at Azcon Metals, where he serviced Class 1 railroads and raw material supply for steel mills, (2) at Zaner Financial Services, where he focused on middle and back-office clearing of futures trades, and (3) as a quantitative analyst, modeling commodity markets at the Colorado School of Mines. He has advised on complex financial products, including swap structures, and written extensively on topics such as copper market outlooks and the role of metals in economic growth. He has also served as a public speaker, presenting at the E-Scrap Conference and at the Institute of Scrap Recycling Industries as well as contributing to publications such as *Kitco News* and *Recycling Today*,

His applied research has been shared at conferences and workshops hosted by institutions such as the Critical Materials Institute, the Federal Reserve Bank of Kansas City, and various international policy organizations. His expertise in economic policy and resource management is complemented by his work in developing marketing strategies for metals recycling and his insights into lithium and critical mineral markets. Mr. Pollan is a recognized leader in his field, with intimate knowledge of global mining networks, including close ties to industry professionals in the United States and globally.

Scott Pollan holds a M.S. in Mineral and Energy Economics from the Colorado School of Mines, a B.S. in Earth Science from Montana State University – Bozeman, and continues to engage in research and thought leadership, contributing to the advancement of knowledge in metals, mining, and market dynamics.

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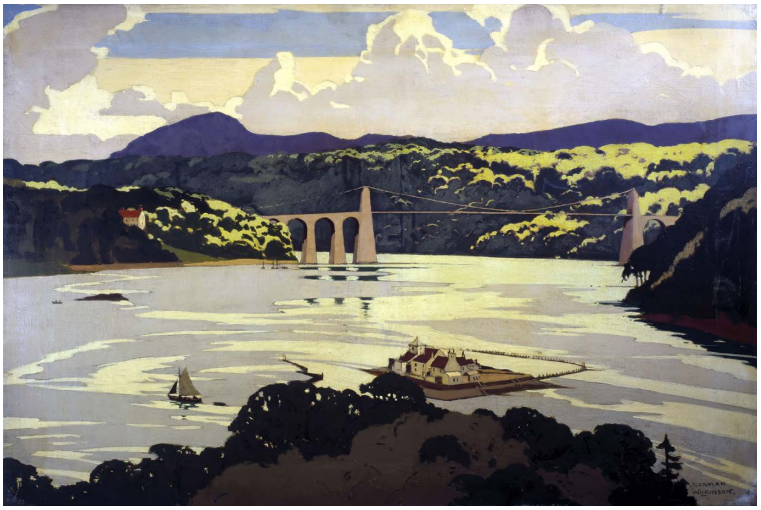

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