Powering the Future in a Sustainable way: Lithium Analysis and Forecasting

Mario Tapia

Program

01

Lithium demand factors

Key aspects of the increasing demand of lithium worldwide

02

Lithium time series

Comparison of lithium exports in Chile and Australia

03

Explainability analysis

Linear regression, Bass model, GBM, Competition model

04

Forecast

Holt's Exponential smoothing, KNN regression, ARIMA

05

Conclusions

Summary of the main findings

06

Future of lithium

Expectations in the Lithium market for the future

01

Lithium demand factors

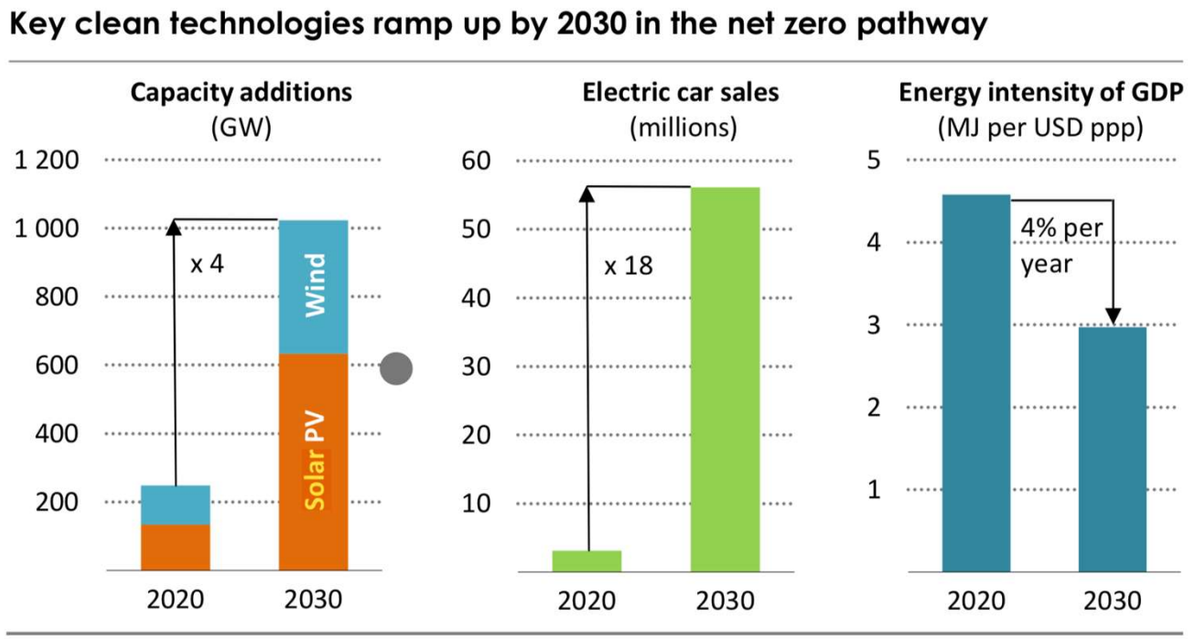
Key aspects for understanding the current demand for lithium

Net Zero by 2050

- To achieve global net-zero emissions by 2050 the conversion to electric transport is a cornerstone[1]

Source: [1]IEA (A Roadmap for the Global Energy Sector)

A clean technology expansion by 2030 is needed

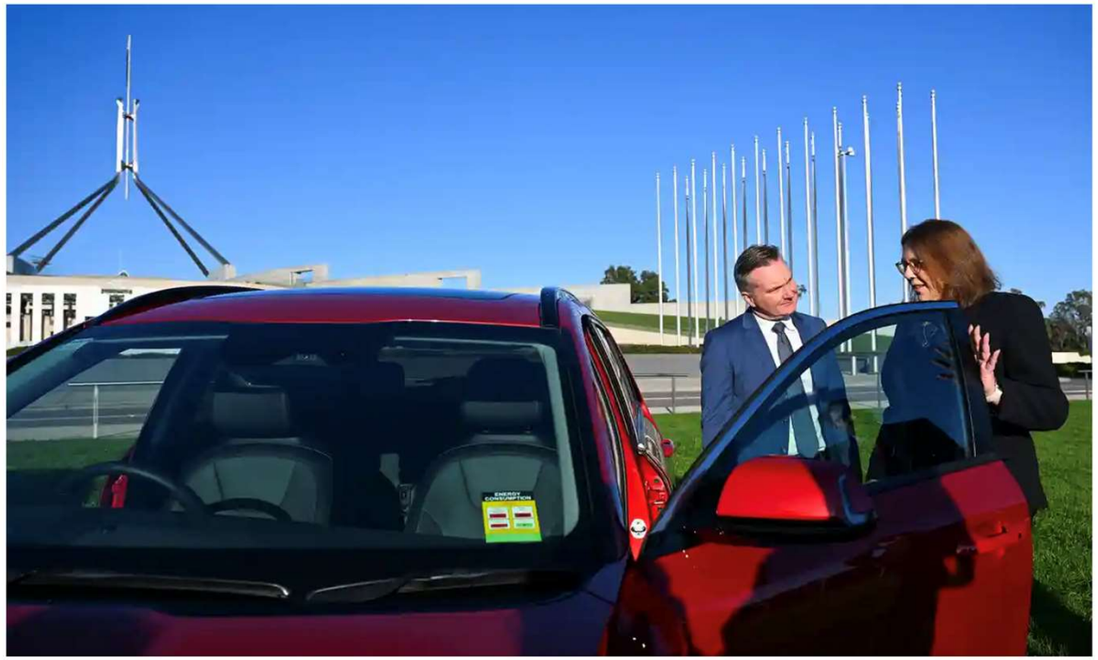


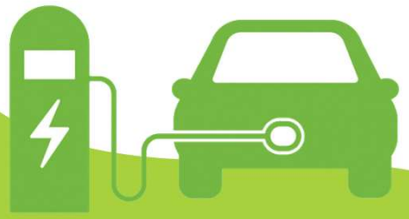
Note: MJ = megajoules; GDP = gross domestic product in purchasing power parity.

Source: IEA (A Roadmap for the Global Energy Sector)

Sales of electric vehicles surge as fast-charging sites double across Australia in a year

EVs made up just 2% of new car sales in May 2022, but now 8.3% of new car sales in 2023 are battery powered





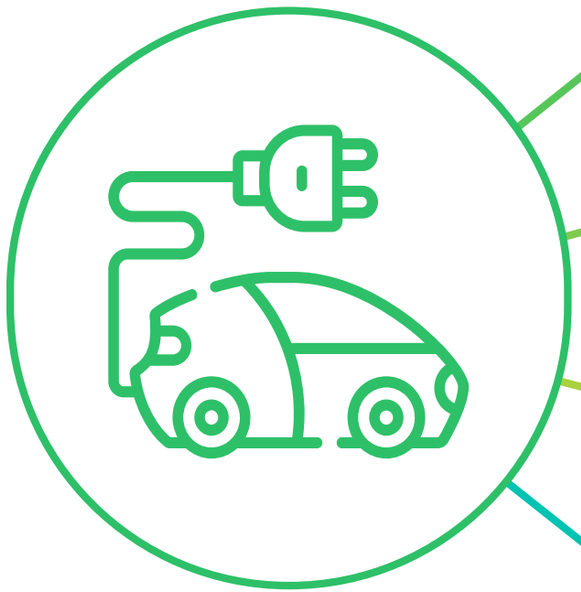
Source: The Guardian

Sales of **electric vehicles** surge as fast-charging sites double across **Australia** in a year

EVs made up just 2% of new car sales in May 2022, but now 8.3% of new car sales in 2023 are battery powered

Source: The Guardian

Lithium: From the nature to an electric vehicle



01 Lithium extraction

02 Conversion to Lithium Carbonate

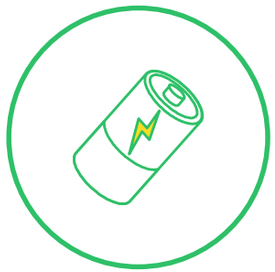
03 Production of **Li-ion batteries**

04 EV battery pack assembly

What is Lithium?

Chemical Element

Abundant Element

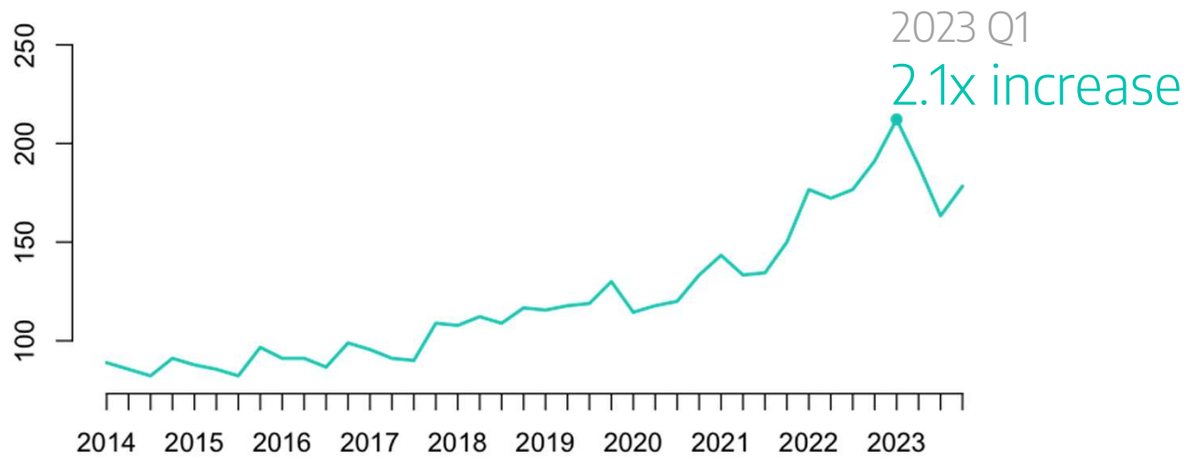


Crucial for Batteries

Google Trends Interest over time

Electric vehicles

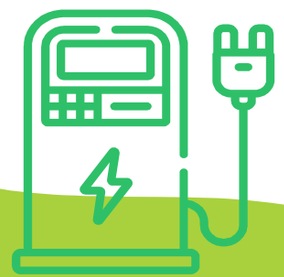
Lithium



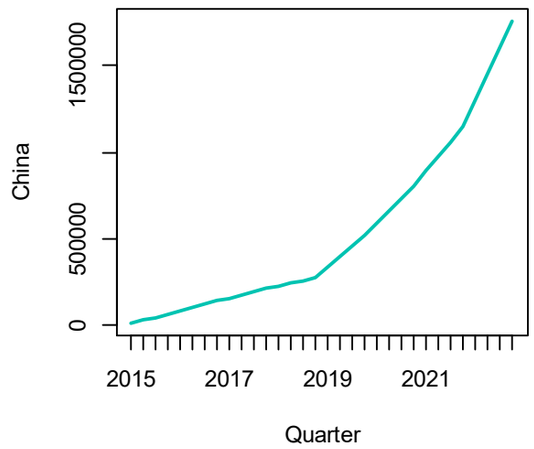
Source: Google Trends

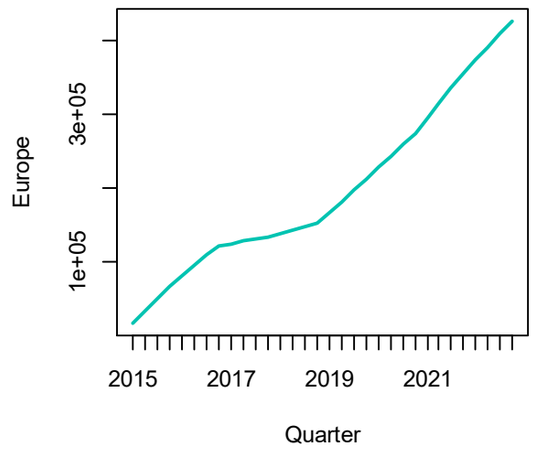
Electric chargers Number of fast and slow chargers

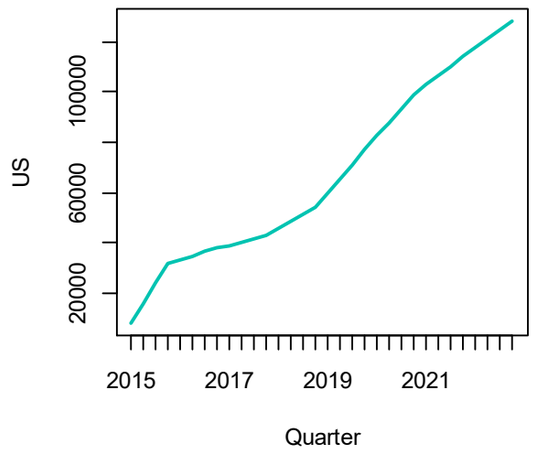
- Increasing trend in electric chargers
- China stands out as the country with the greatest number of fast[1] and slow[2] electric chargers available

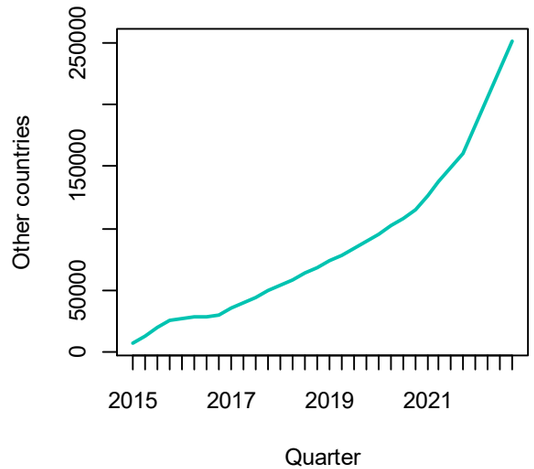


Source: [1]IEA (fast chargers), [2]IEA (slow chargers)



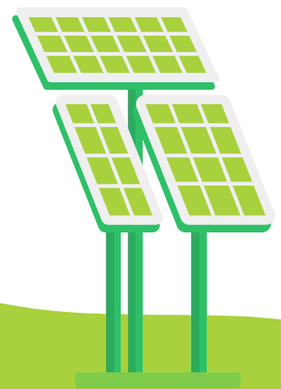






Solar investment Billion USD

- It is related to energy storage
- It can also be seen as an indicator of interest in renewable energies



Source: Statista

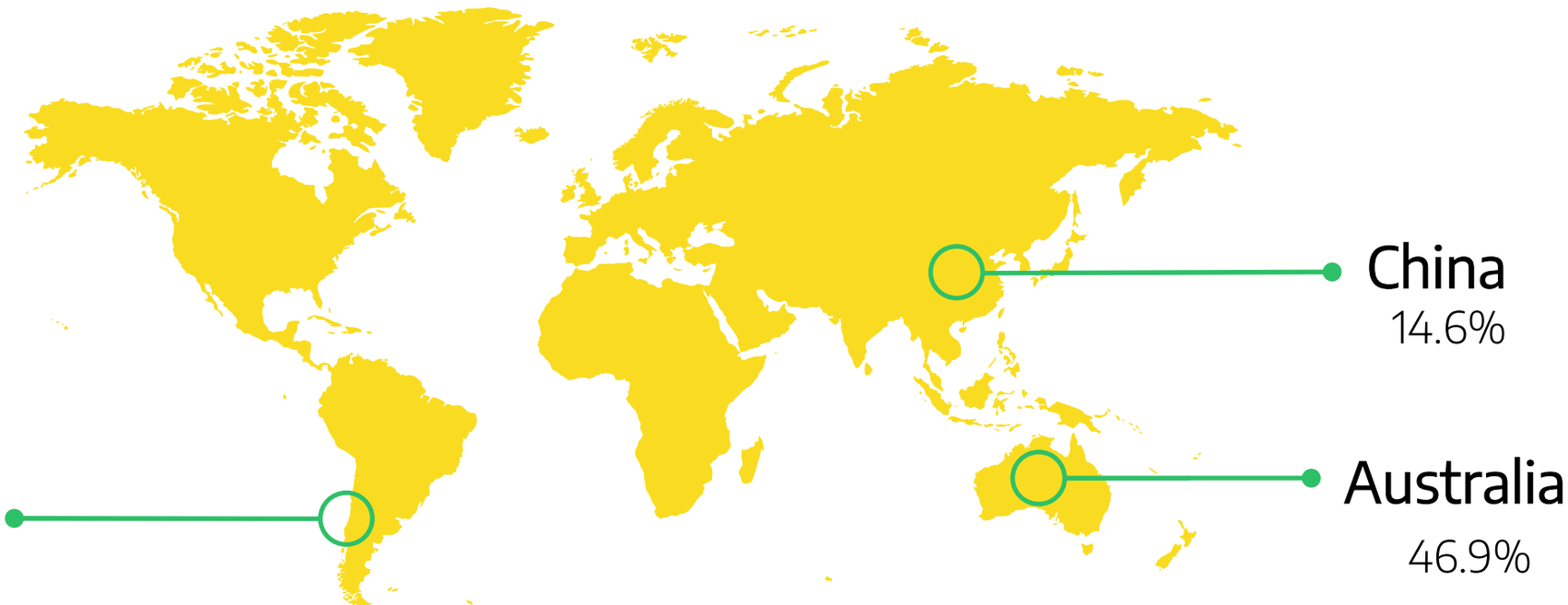
02

Lithium Time Series

About the main time series

Lithium production Worldwide map (2022)

Australia and Chile account for the **77%** of the global production



Source: United States Geological Survey

Lithium production Australia and Chile

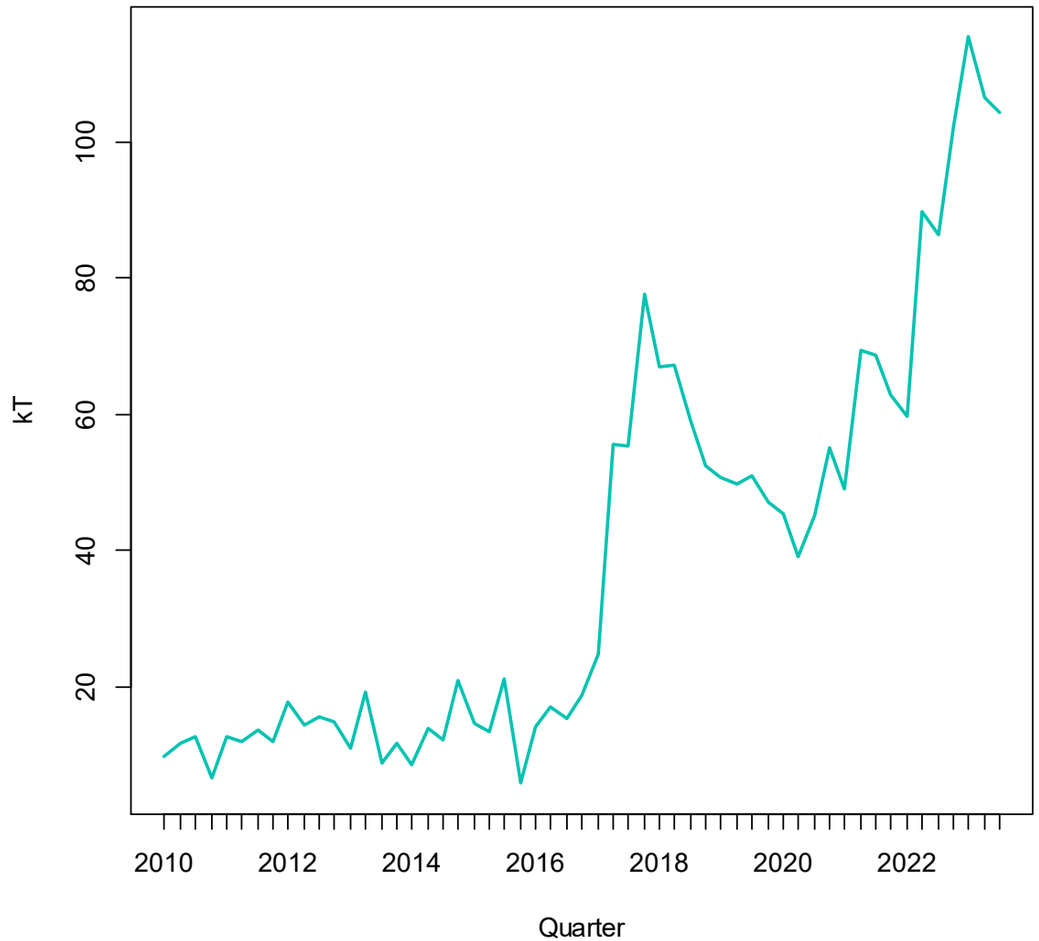
- Australia extracts lithium from hard rock mines
- Chile extracts the mineral from brines
- Common unit of measure: Lithium Carbonate Equivalent (LCE)
- We will focus on the exports of each country (quarterly data)

Pilbara Minerals' Pilgangoora lithium tantalum mine, Australia

Brine pools and processing areas at SQM's lithium mine on the Atacama salt flat, Chile

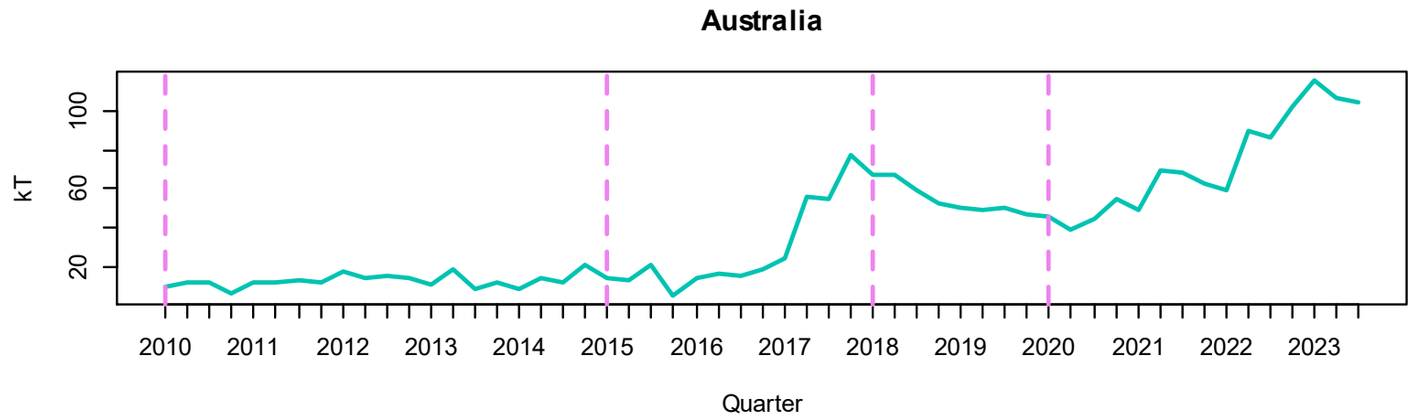
Lithium exports Australia

- Significant rise from 2016 to 2018
- Decline from 2018 to 2020
- Recovery from 2020 onwards
- Most of Australia's exports go to China



Source: Australian Government, Department of Industry, Science and Resources

Lithium Australia events



2010

China began granting subsidies to EV buyers[1]

2015

China's government announced that it would phase out subsidies progressively from 2016 and by the end of 2020[2]

2018

Excess of supply, slower demand growth for EV, criteria to qualify for subsidies became more stringent in China[3]

2020

China's government extended the subsidies by two years to the end of 2022, due to the pandemic and the economic downturn[4]

Sources:

1 China's National Development and Reform Commission

2 International Council on Clean Transportation

3 Reuters news agency

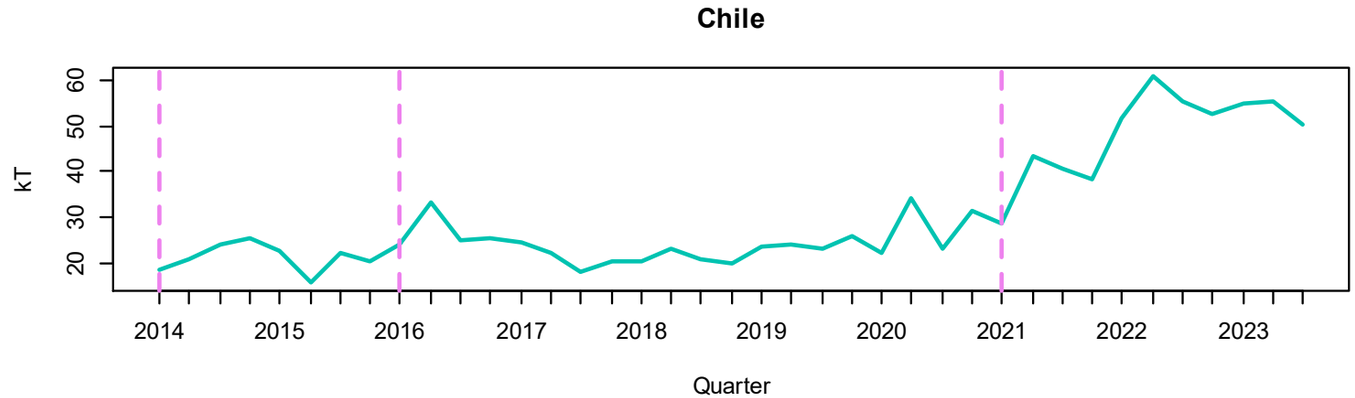
4 Ministry of Finance of the People's Republic of China

Lithium exports Chile

- Chile started a National Lithium Commission in 2014
- Rise from 2015 to mid-2016
- Decline from mid-2016 to 2018
- Significant rise from 2021 onwards, most of Chile's exports go to China, Japan and South Korea

Source: National Customs Service of Chile

Lithium Chile events



2014

Decree: National Lithium Commission in 2014

2016

Chile experienced a decrease in its lithium production and market share[1]

2021

In the first five months of 2021, Chile increased significantly the exportation of lithium carbonates (China, Japan, South Korea)[2]. Most of Chile's exports go to China[3]

Sources:

[1] Mining.com

[2] Reuters news agency

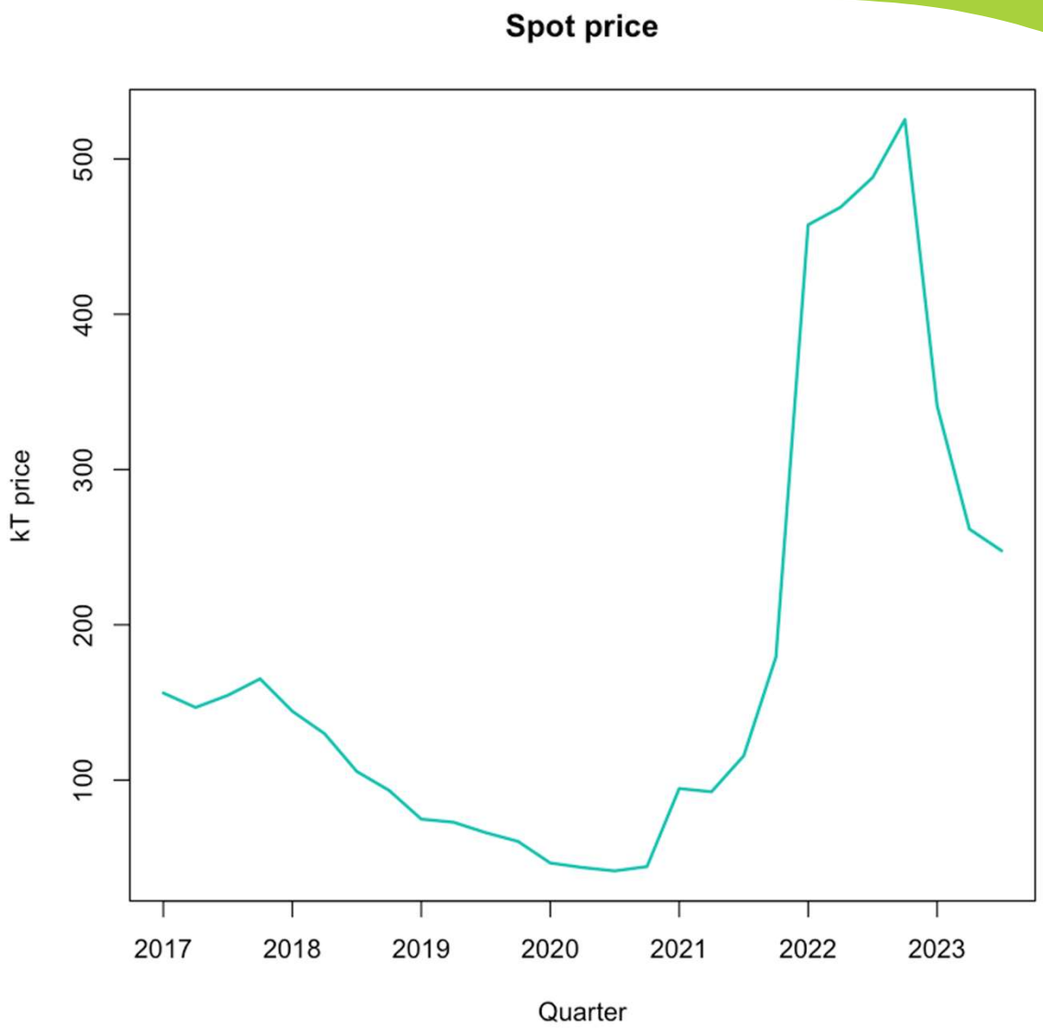
[3] World Integrated Trade Solution

Lithium exports Australia and Chile

- Australia has a larger experience in Lithium extraction and exploration
- Both countries have experienced an increase in their exportations since 2020.
- Mainly explained by the growing interest in this product

Lithium Carbonate Price per kilotonne (CNY)

- China spot price
- Exponential increase from 2020
- Slowing demand causing the price to fall.



Source: Investing

Stock Prices Lithium Companies

Albemarle Corporation

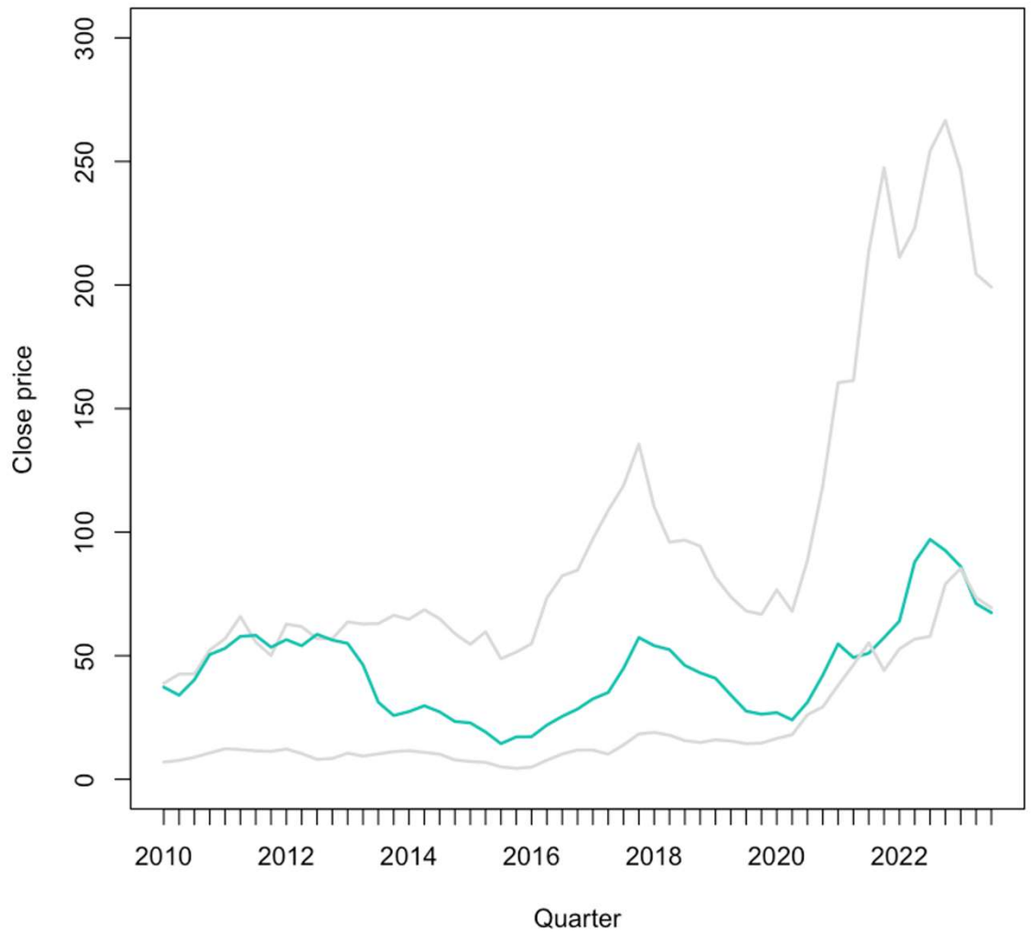
- US based company
- World's largest lithium producer
- Presence in Australia and Chile

Source: Yahoo! Finance

Stock Prices Lithium Companies

Sociedad Química y Minera de Chile S.A. (SQM)

- Chilean company
- World's second-largest lithium producer

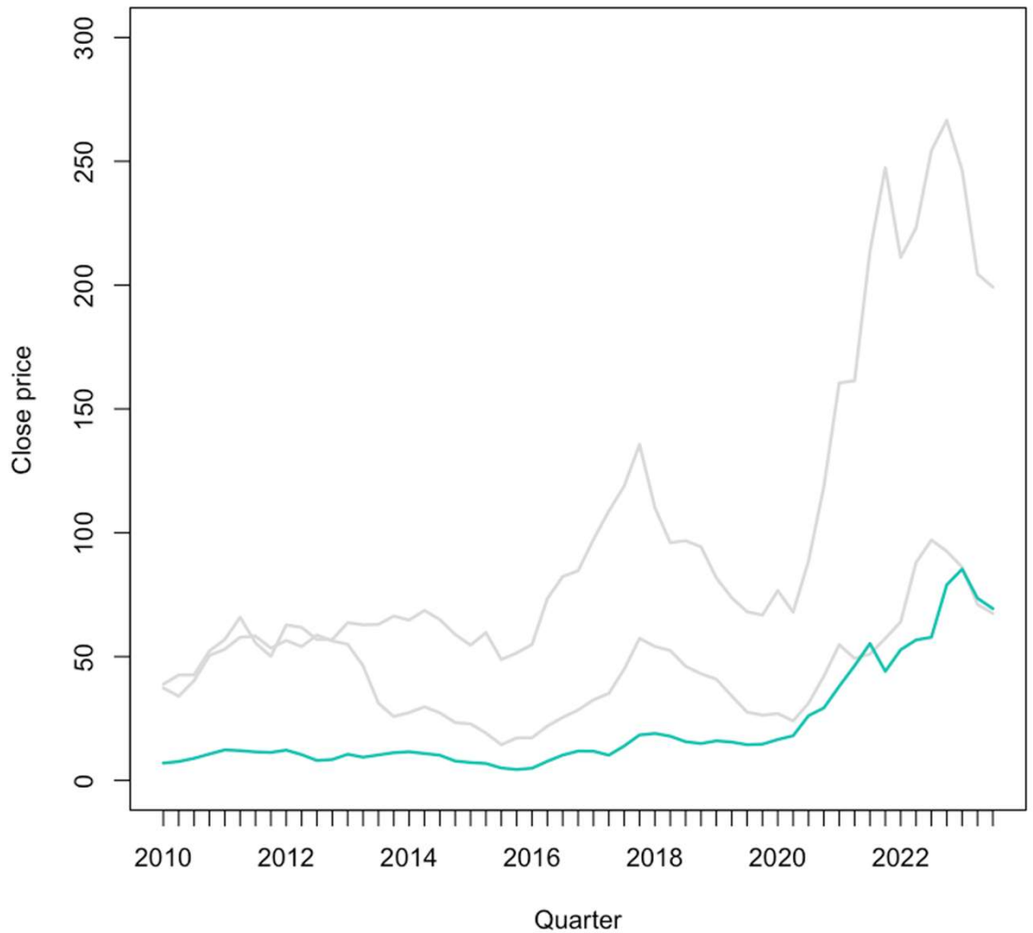


Source: Yahoo! Finance

Stock Prices Lithium Companies

Mineral Resources Limited

- Australian company
- Operates hard rock lithium mines in Western Australia



Source: Yahoo! Finance

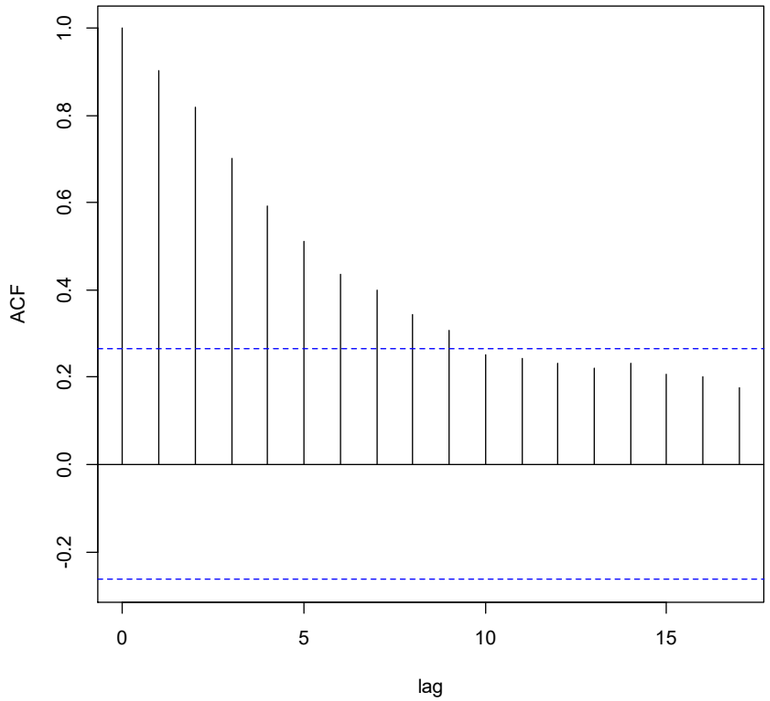
03

Explainability Analysis

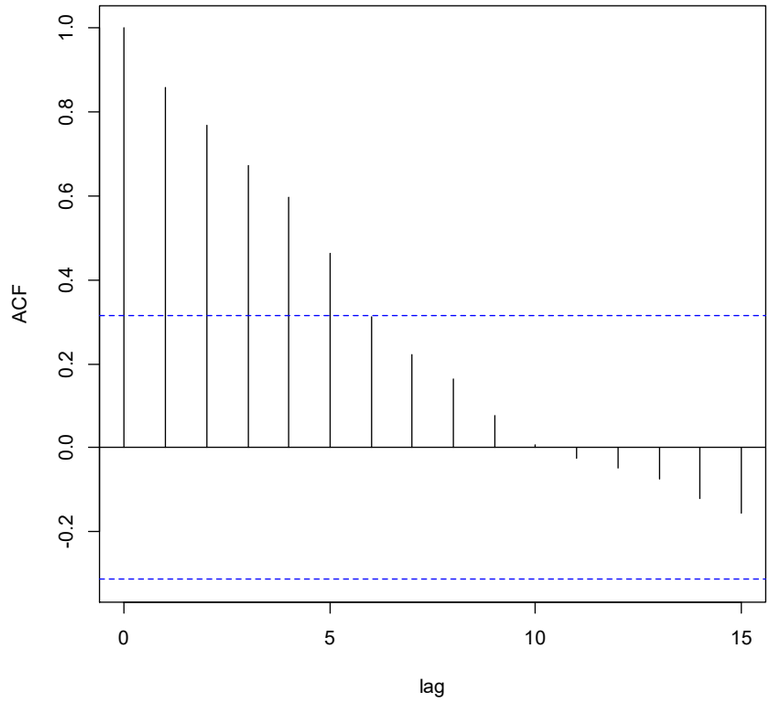
Linear Regression, Bass model, GBM, Competition model

Lithium time series Australia and Chile

Australia



Chile

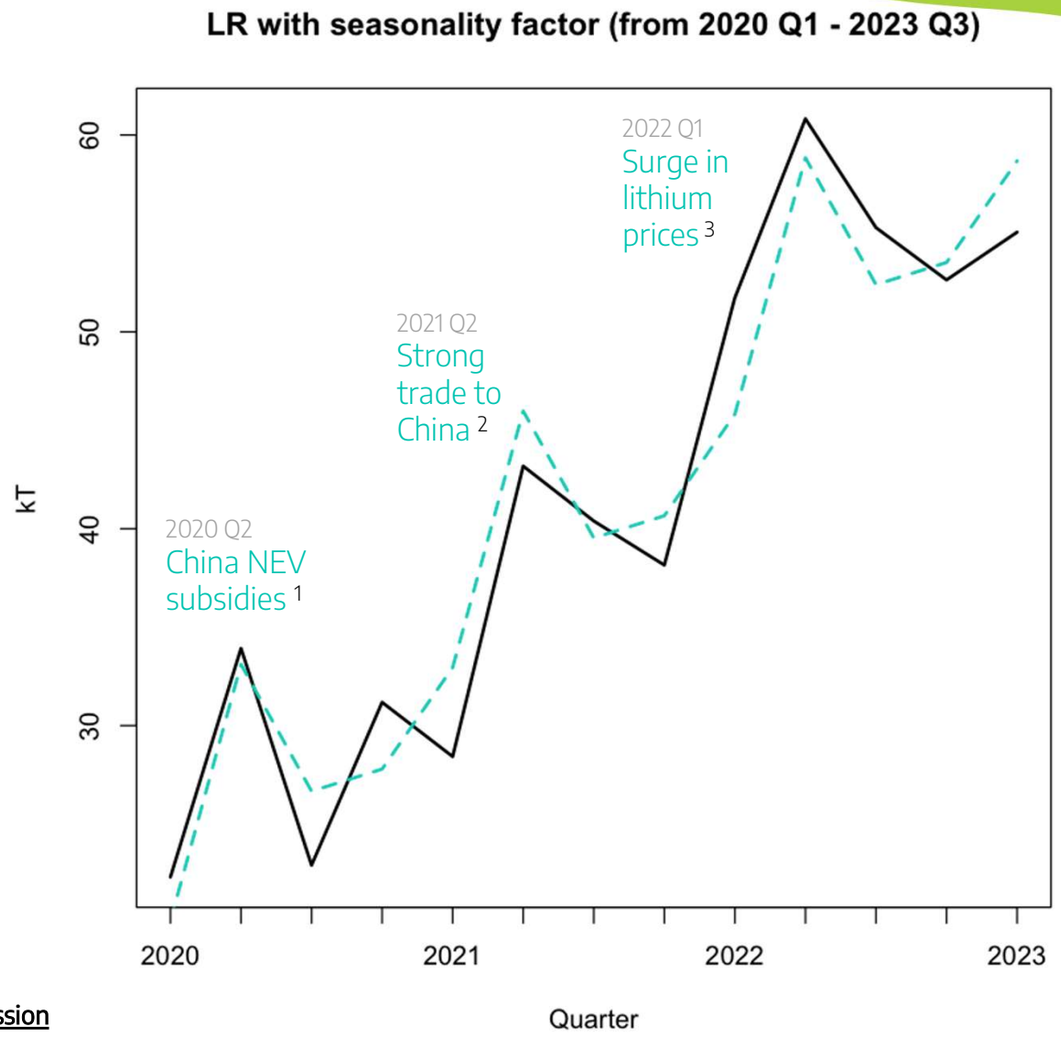


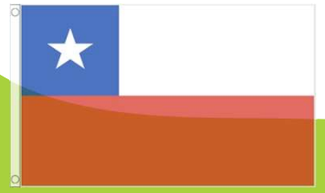
- Both cases: Trend is significant and Seasonality not significant (Linear Regression + season + trend) but...

Linear Regression Window from 2020 onwards

Chile

- Trend is significant
- Q2 is slightly significant, compared to Q1
- $R^2 = 0.94$





Sources:

1 China's National Development and Reform Commission

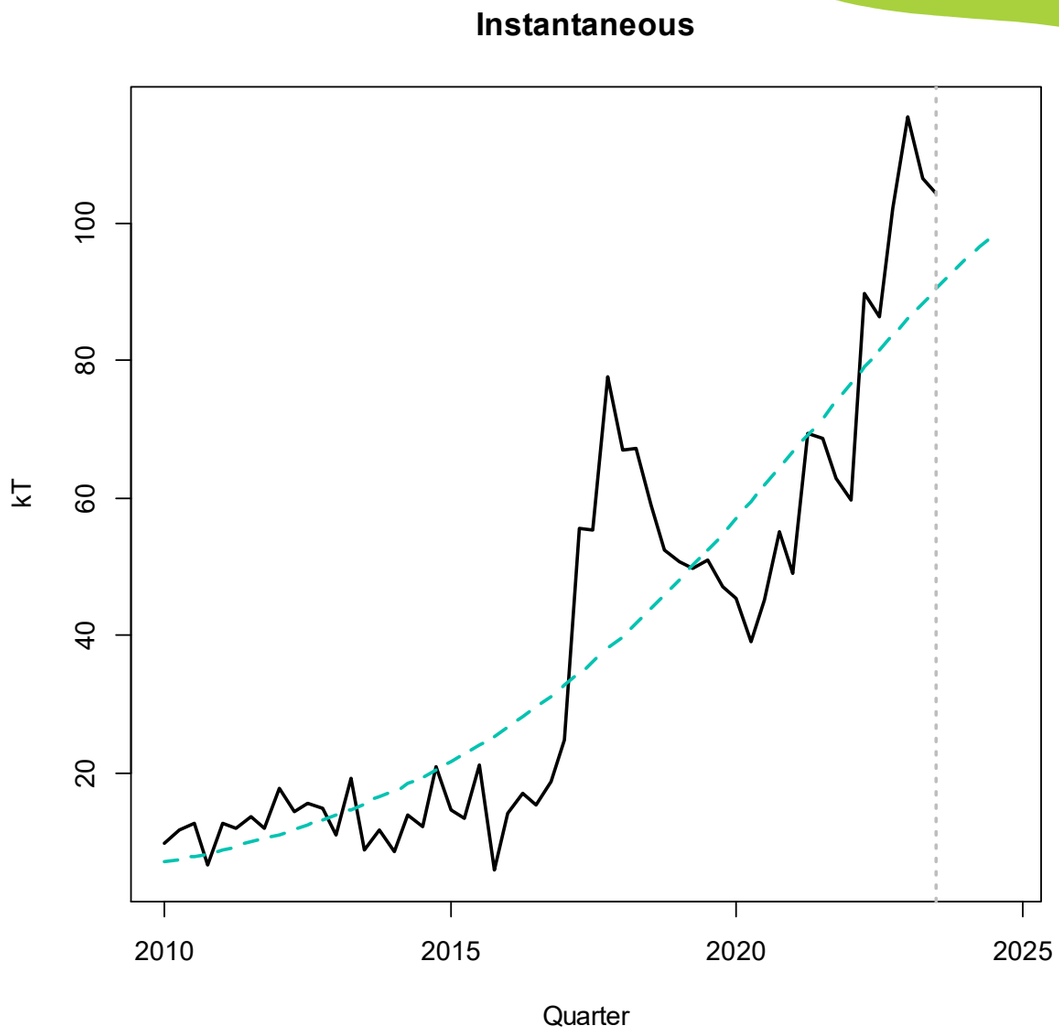
2 S & P

3 S & P

Bass model Australia

- Forecast for one year
- Slightly pessimistic
- Innovation and imitation are significant

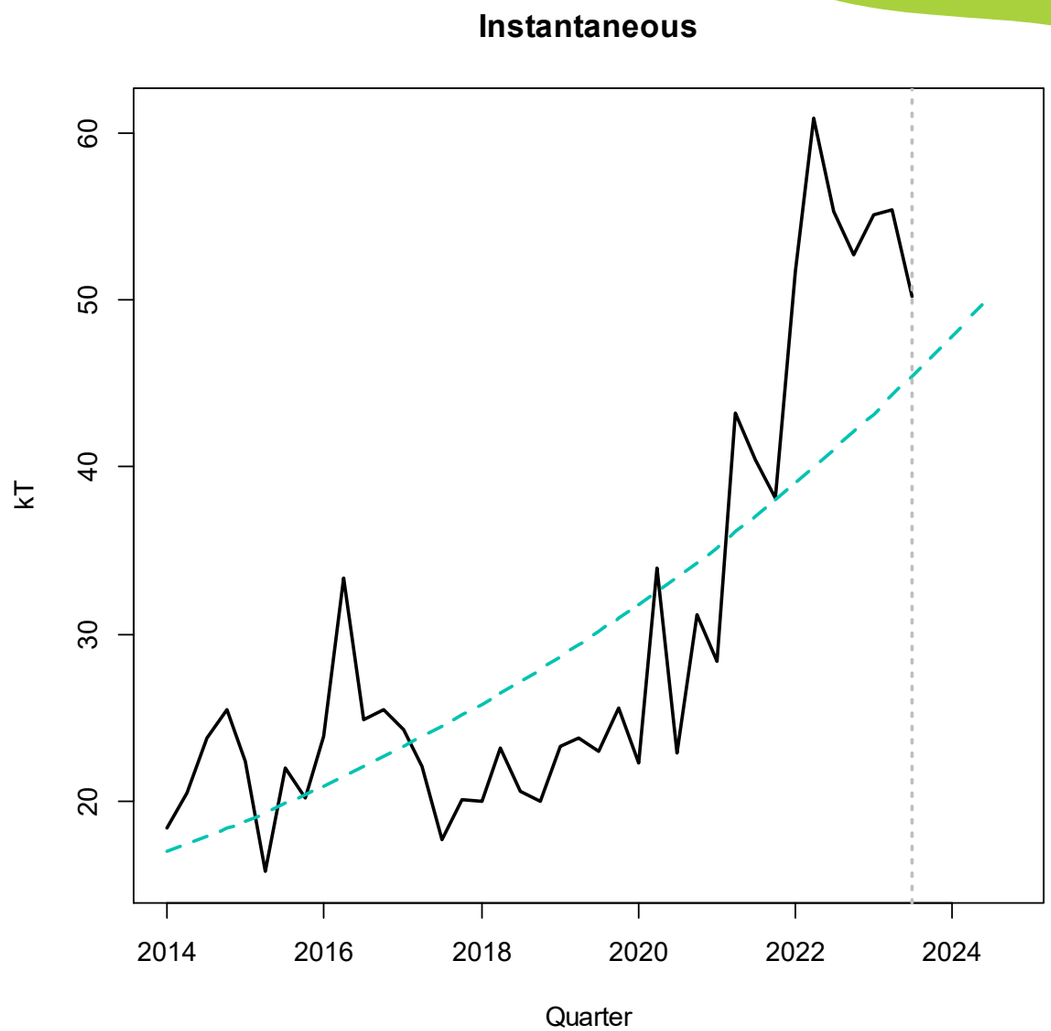
Market Potential	Innovation	Imitation	R^2
6.99e+03**	9.7e-04***	5.9e-02***	0.99



Bass model Chile

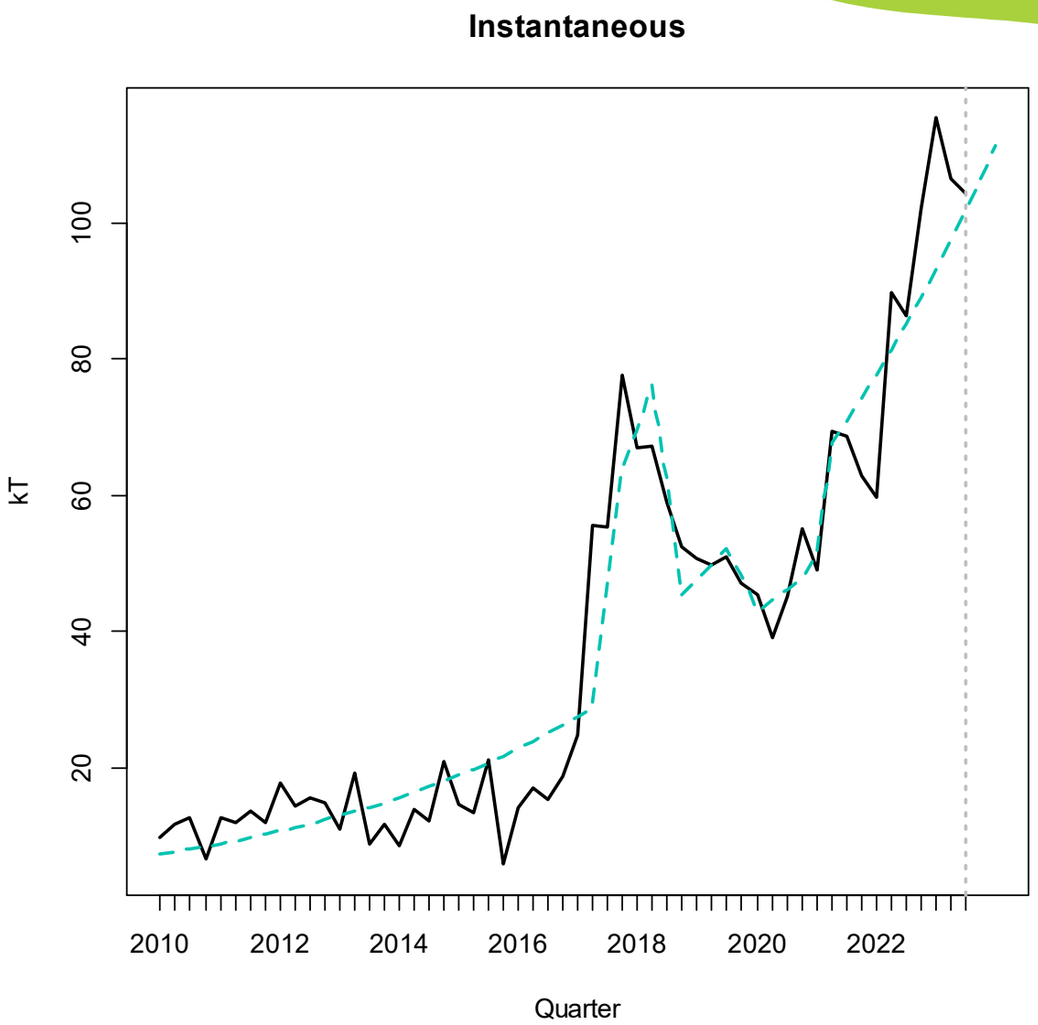
- No significant parameters
- Forecast for one year
- No indication that the peak has been reached

Market Potential	Innovation	Imitation	R^2
5.67+04	2.9-04	2.66-02	0.99



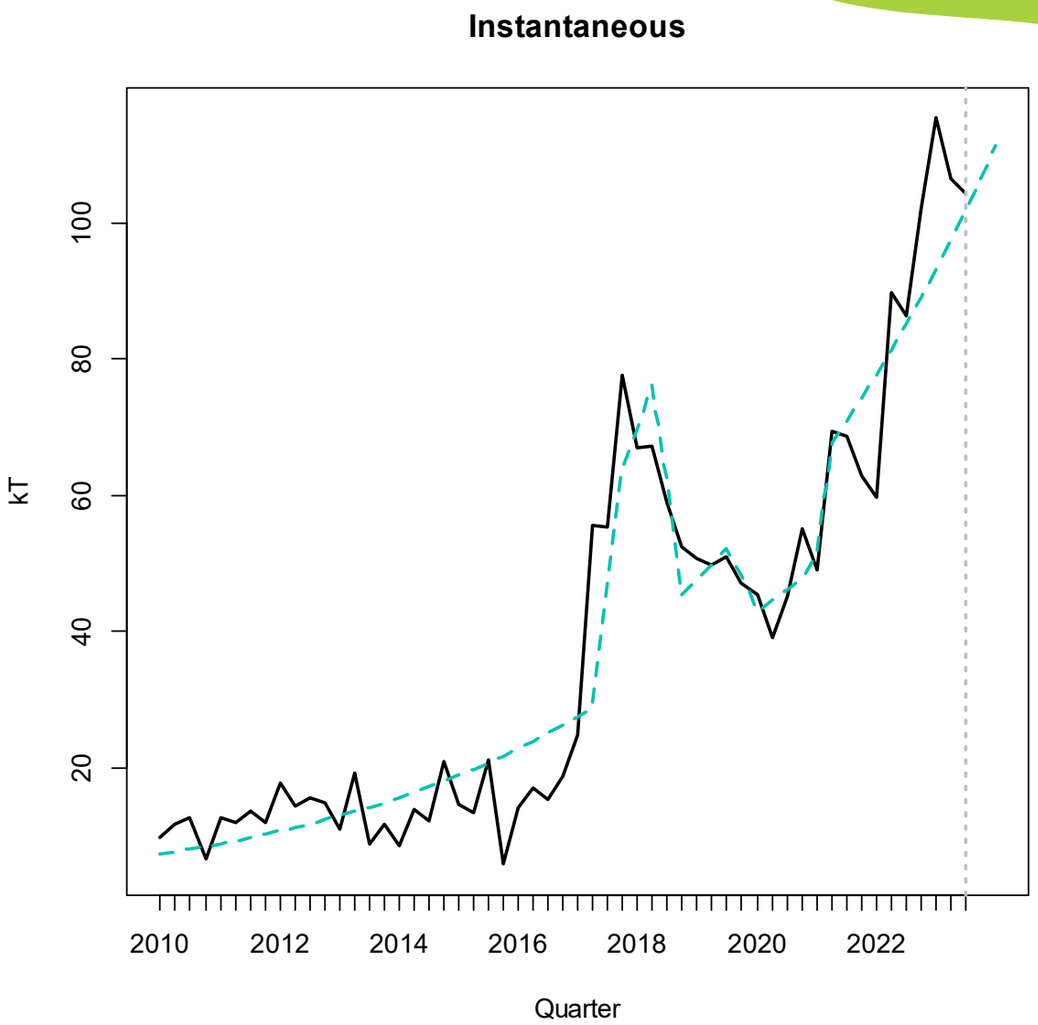
GBM Australia

- Double Rectangular shock between **2017.Q2 – 2018.Q2**, and **2019.Q4 – 2021.Q1**
- These periods could be approximately explained with the excess of supply of 2018, and the extension of the subsidies in 2020



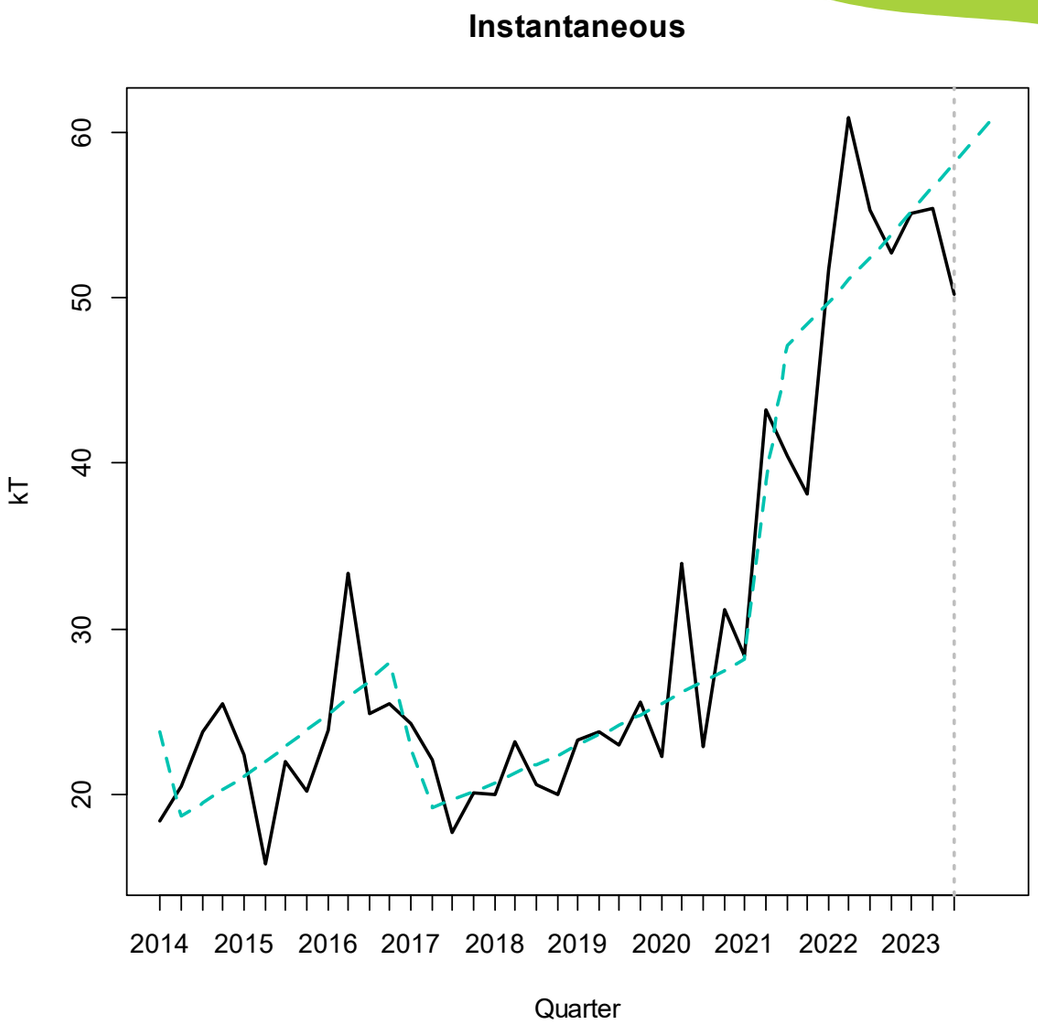
GBM Australia

- R^2 = 0.998889
- Significant auto-correlated residuals (better model found by using Double Exponential shock)
- Expected out-of-sample behaviour (four quarters)



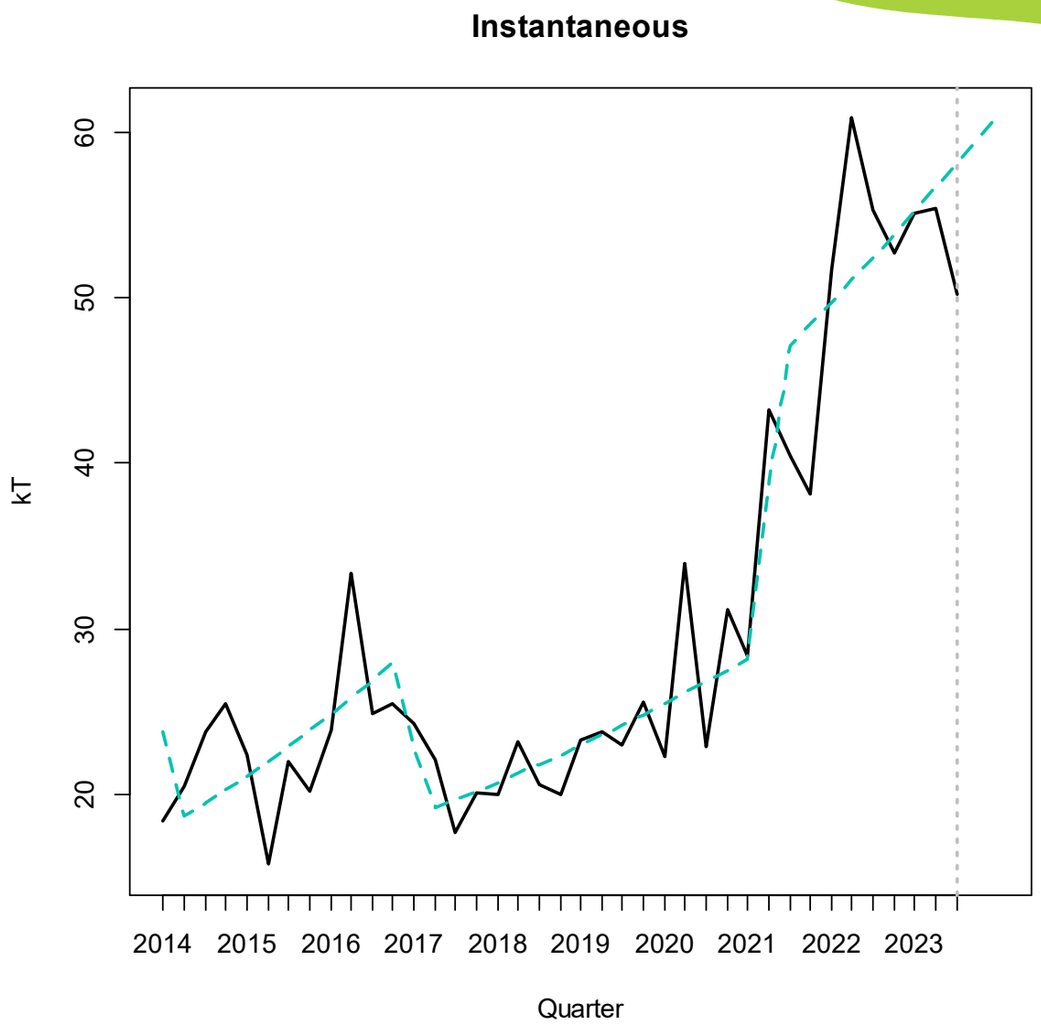
GBM Chile

- Mixed shock at **2016.Q4** (rectangular), and **2021.Q1** (exponential)
- These periods could be approximately explained with the decrease in lithium production and market share of 2016, and the increase in exportations to China, Japan, and South Korea from 2021 onwards



GBM Chile

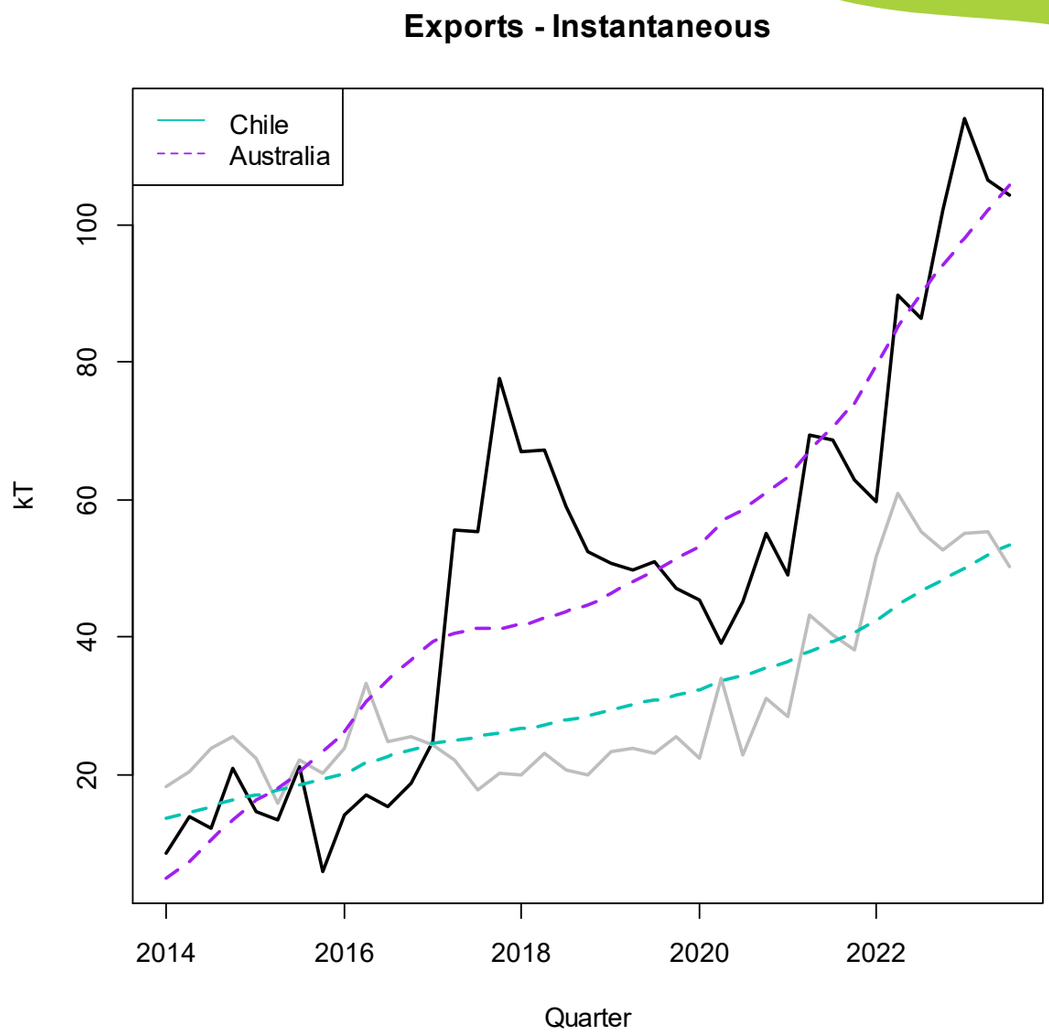
- R^2 = 0.999864
- Significant auto correlated residuals
- Expected out-of-sample behaviour (four quarters)



Competition model Australia vs. Chile

- Both series since 2014.Q1
- Chile collaborates with Australia, but Australia competes with Chile
- Both series show a better adjustment than Bass model

q1c	q2-gamma	R^2
1.47e-01**	-4.2e-03	0.83



04

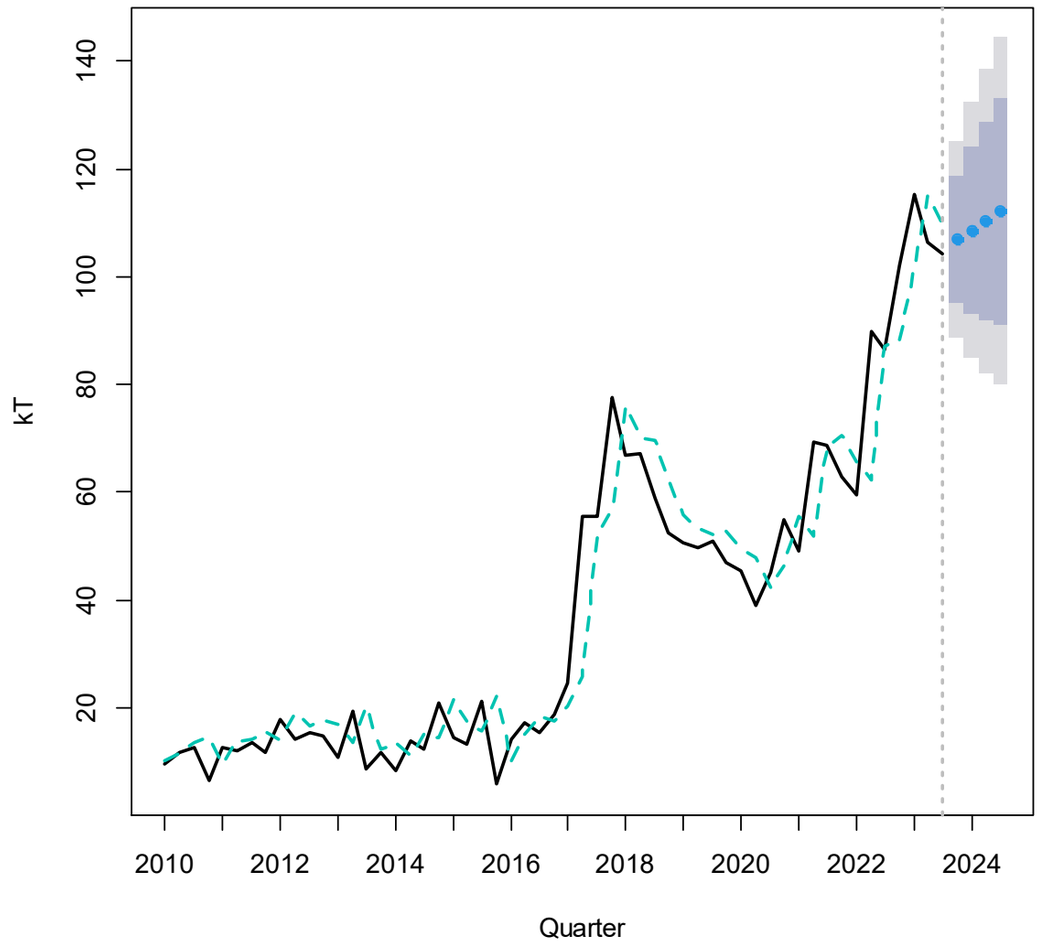
Forecast

Holt’s exponential smoothing, KNN regression, ARIMA

Holt's exponential smoothing Australia

Comments:

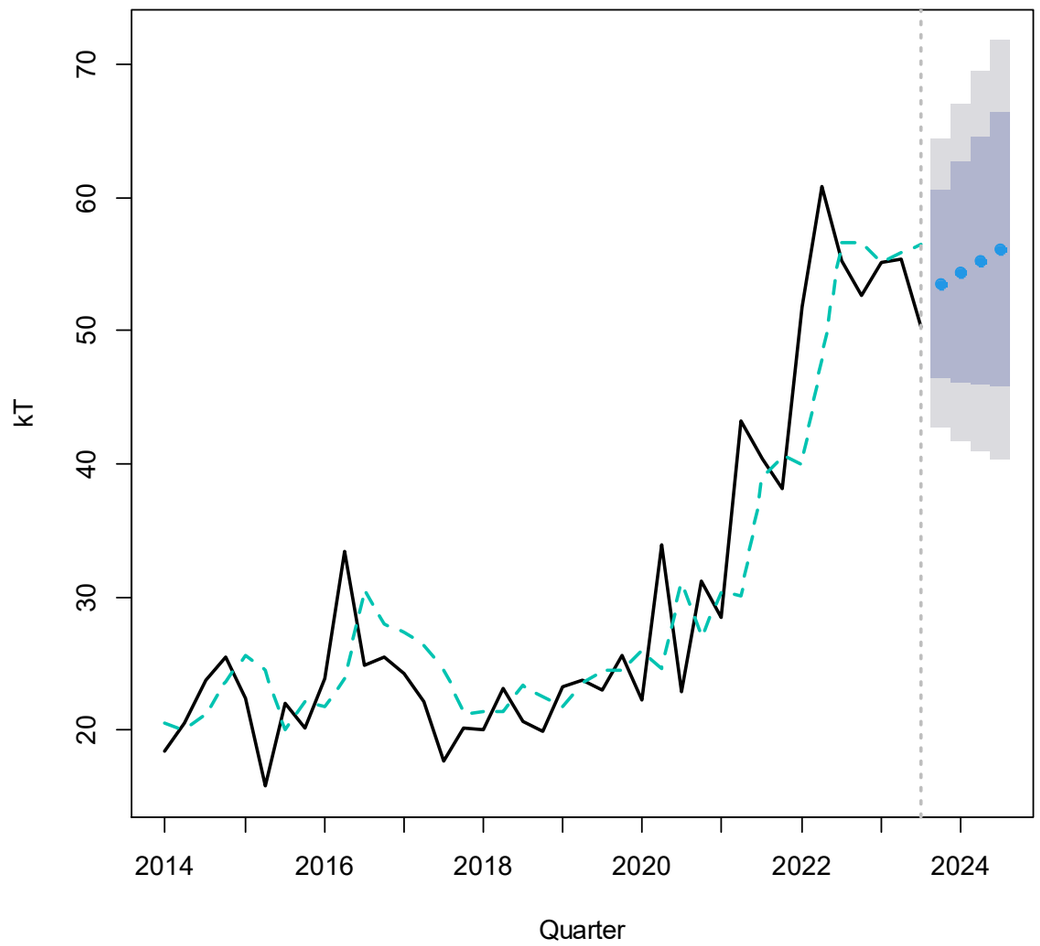
- Smoothing parameter chosen automatically (0.61)
- A time shift is observed
- Holt-Winters does not offer a better solution to this



Holt’s exponential smoothing Chile

Comments:

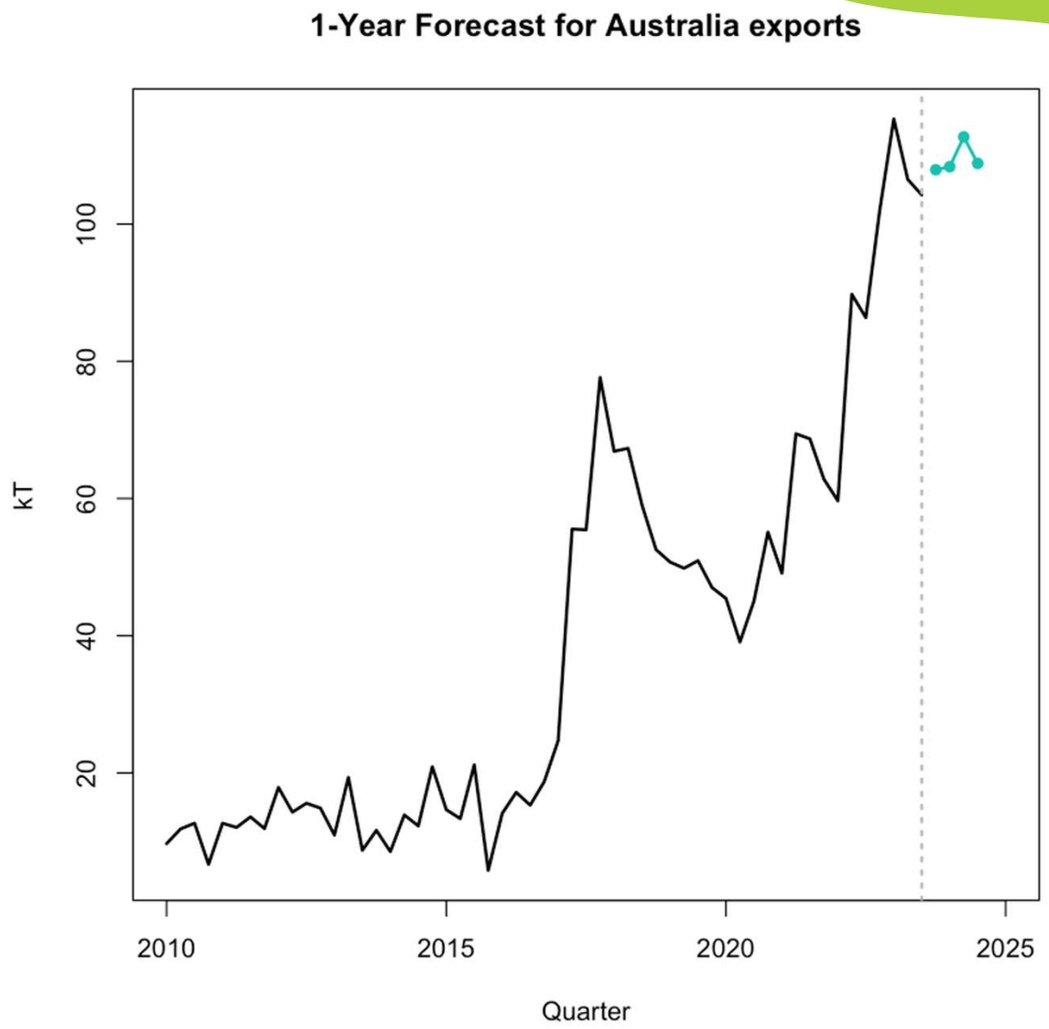
- Smoothing parameter chosen automatically (0.84)
- A time shift is observed
- Holt-Winters does not offer a better solution to this



KNN Regression Australia

Comments:

- KNN adapted to time series using lagged values of the dependent variable[1].
- k = 2
- Recursive strategy for forecast
- Exports to be tightly balanced according to forecast

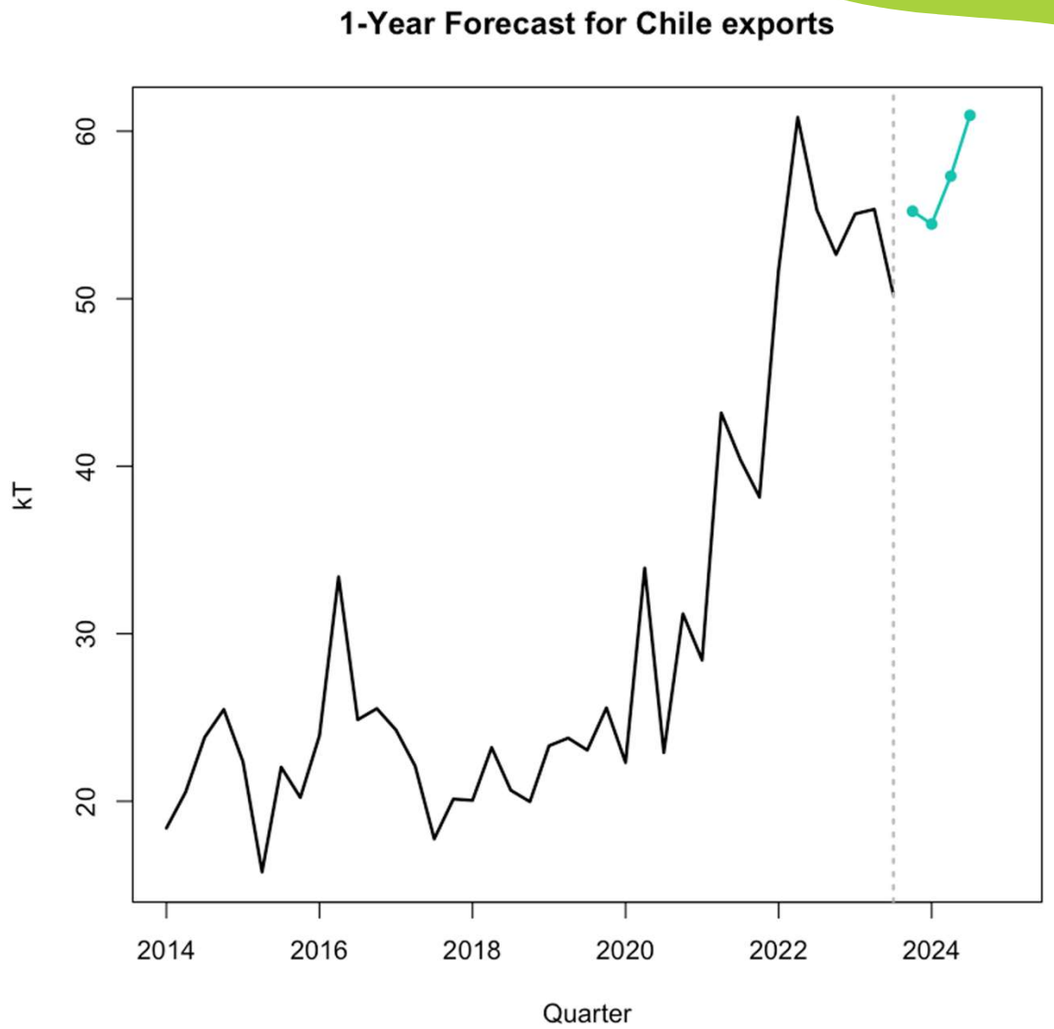


Source: CRAN

KNN Regression Chile

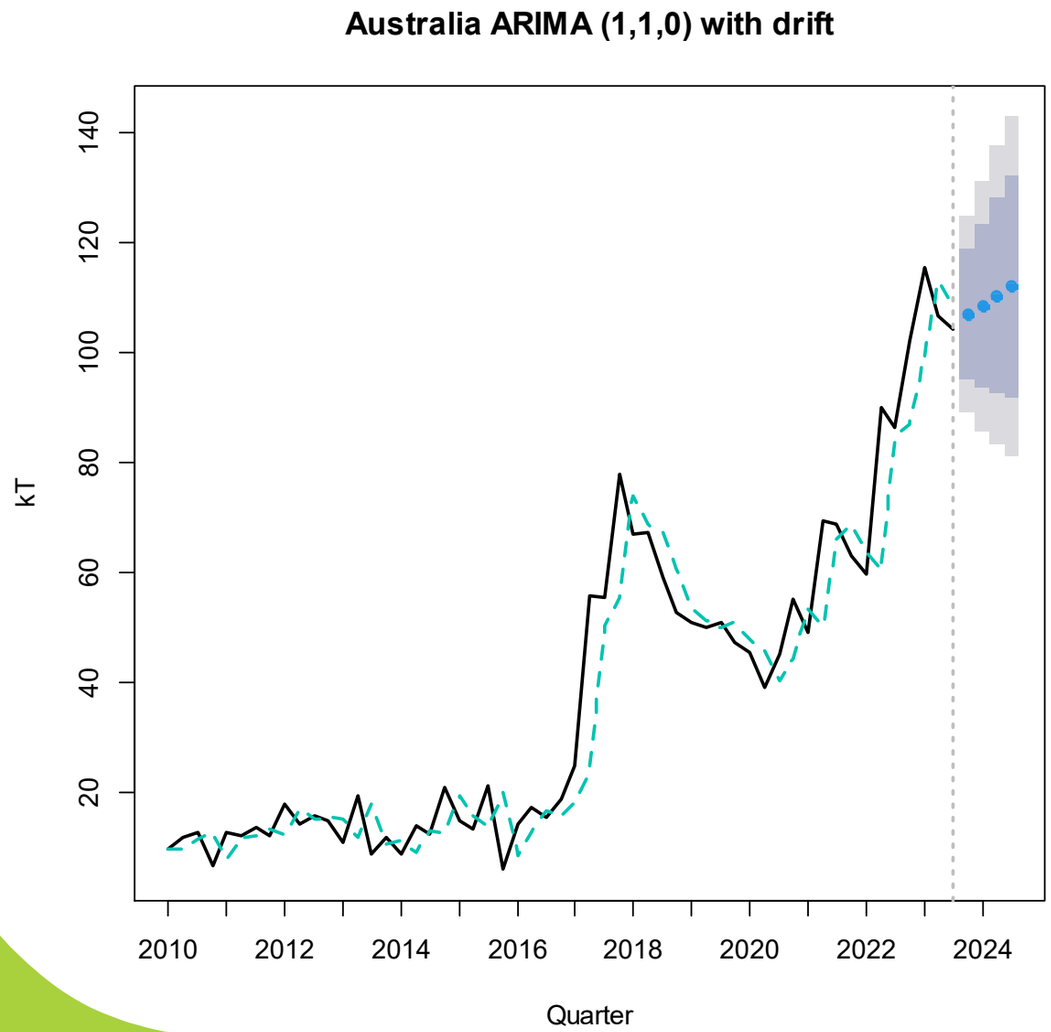
Comments:

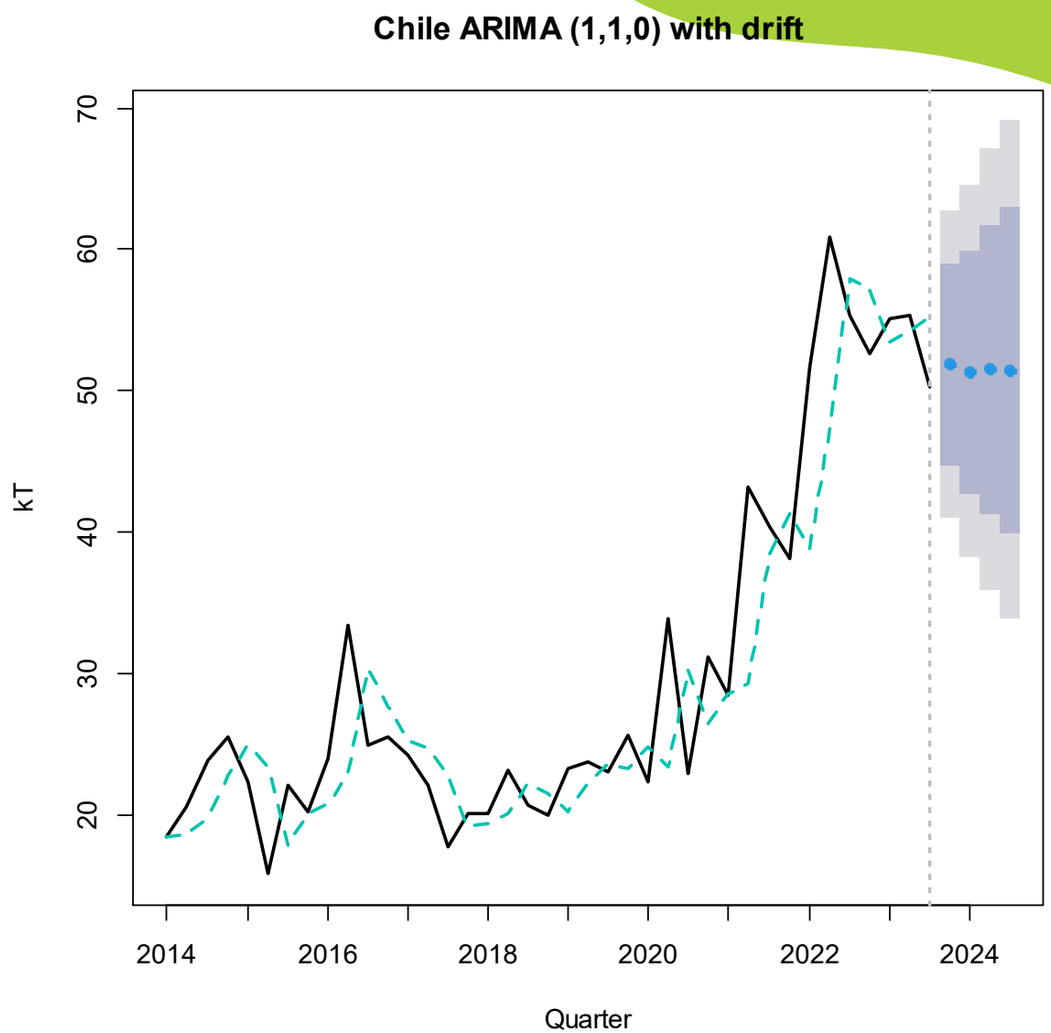
- KNN adapted to time series using lagged values of the dependent variable[1].
- k = 2
- Recursive strategy for forecast
- Optimistic forecast



Source: CRAN

ARIMA Australia and Chile





ARMAX Explanatory Variables

Economic

- GDP
- GDP per capita (working population)
- Yearly variations

Energy related

- Electric Vehicles Stock (China, Europe, USA, Total)
- Fast and Slow chargers (China, Europe, USA, Total)
- Solar Investment

Google Trends

- E-cars (AUS, CHL, World)
- Lithium (AUS, CHL, World)
- Lithium Batteries (AUS, CHL, World)

Stock Market

- Albemarle
- Mineral Resources
- SQM

ARMAX Explanatory Variables

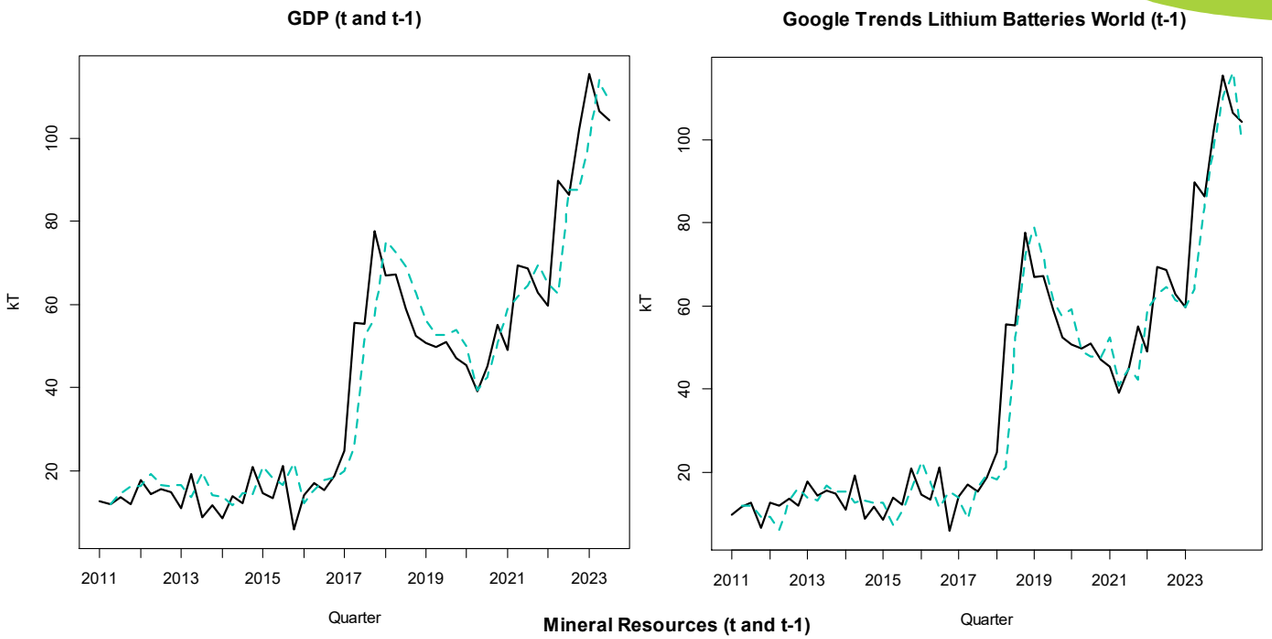
01	Different lags	t = 0, t = t-1, and both
02	Choose Best Adjustment	Based on AIC and model adjustment
03	Forecasting Explanatory variables	Exponential Smoothing or Holt

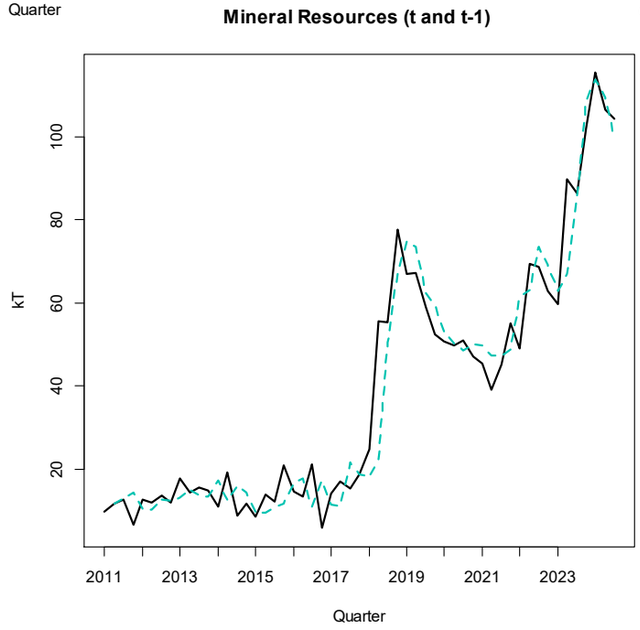
ARMAX Australia

Comments:

- Similar adjustments. Differences in certain periods.

Variable	Time
Mineral Resources	t, t-1
Lithium Bateries World Trends	t-1
GDP per capita Australia	t, t-1



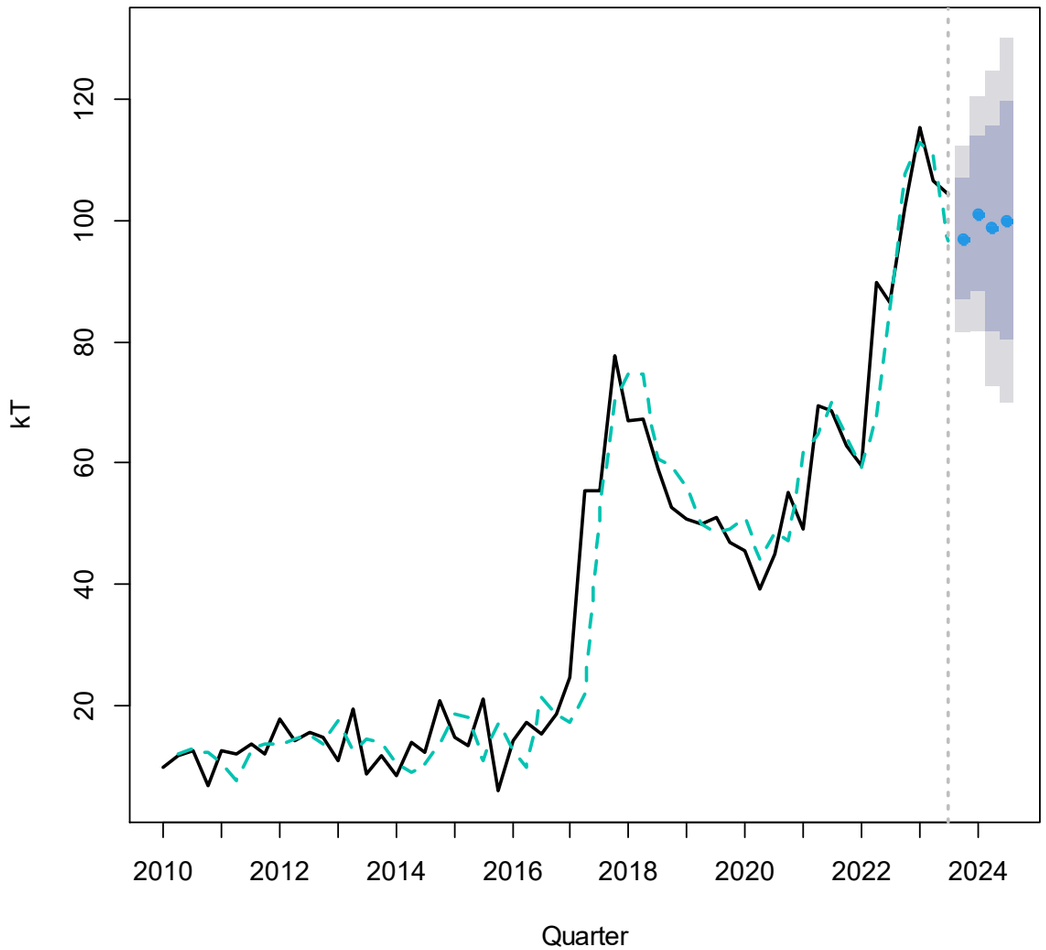


ARMAX Australia

Comments:

- ARIMA(2,1,0) with errors
- Slowly increasing forecasting

Variable	Time	Forecasting
Mineral Resources	t, t-1	Exponential Smoothing
Lithium Bateries World Trends	t-1	Exponential Smoothing

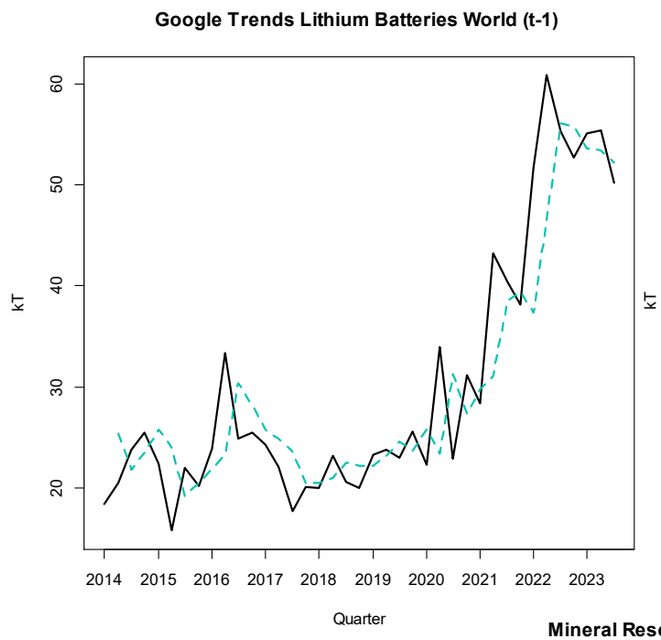


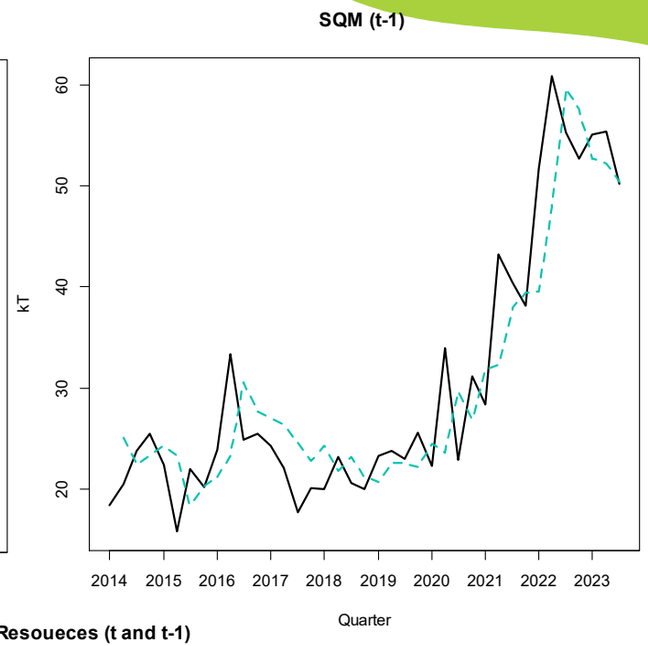
ARMAX Chile

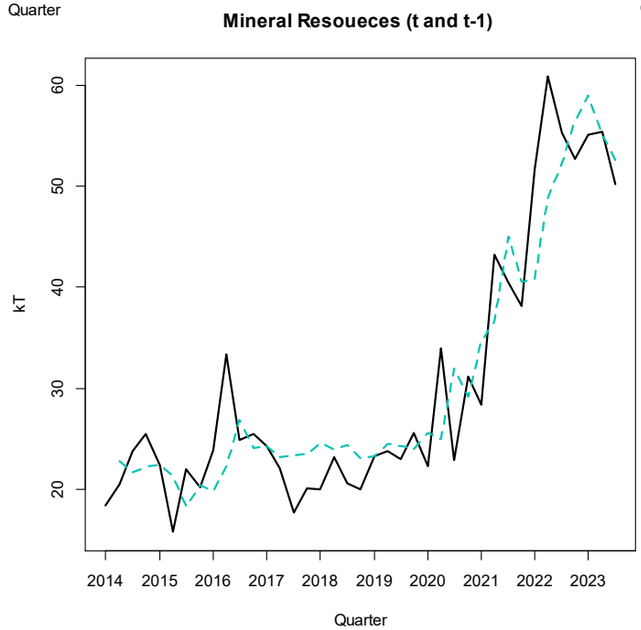
Comments:

- Differences in the adjustment, by period and peaks

Variable	Time
Mineral Resources	t, t-1
Lithium Bateries World Trends	t-1
SQM stock	t-1





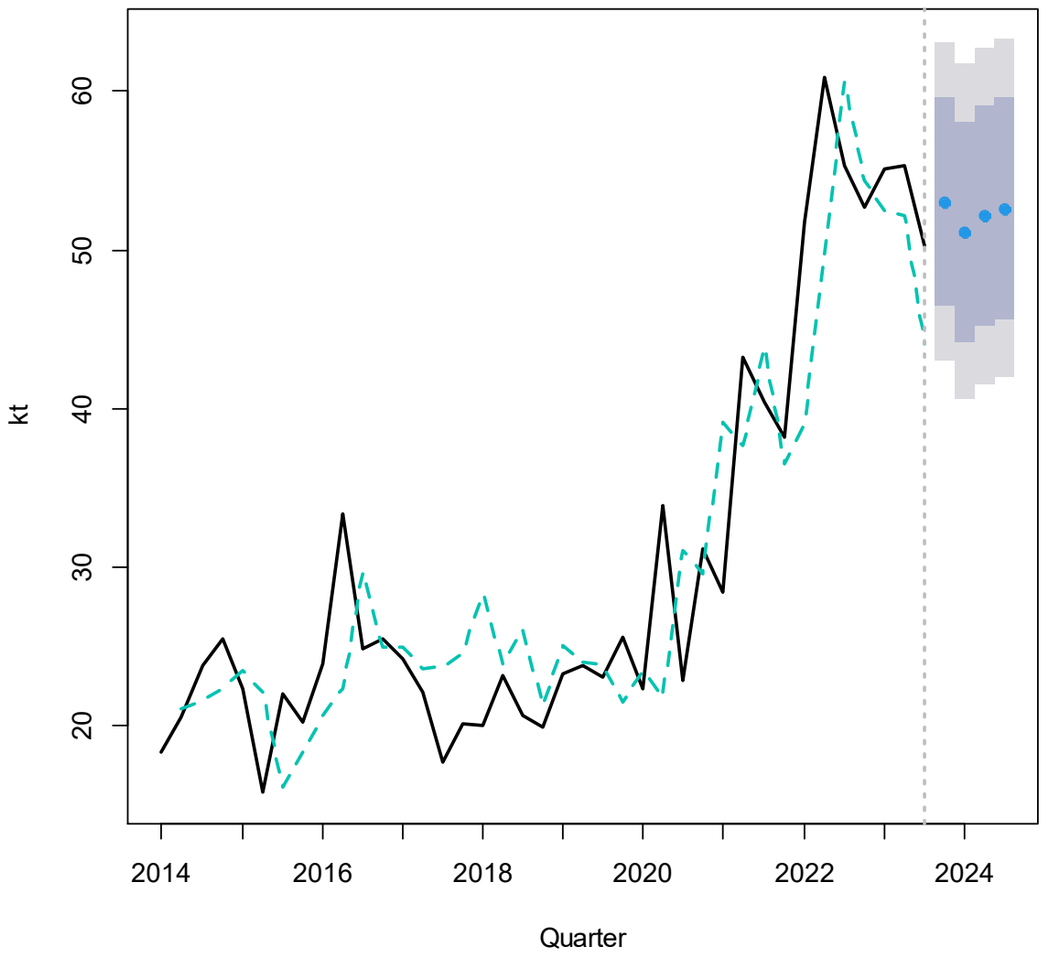


ARMAX Chile

Comments:

- ARIMA(1,1,0) with errors
- Moderate forecasting behaviour

Variable	Time	Forecasting
SQM stock	t-1	Exponential Smoothing
Lithium Bateries World Trends	t-1	Exponential Smoothing
Mineral Resources	t, t-1	Exponential Smoothing



05
Conclusions

Summary of the main findings

Product Growth Australia and Chile

Comments:

- The Bass Model and the Generalized Bass Model help to understand the general growth of Lithium up to now
- The market potential of Lithium has not been reached
- The Generalized Bass Model shows how the shocks impact the dynamics of the lithium export

Forecasting Australia

Model	MAPE
Holt's exponential smoothing	**13.64**
ARIMA(1,1,0)	26.25
ARMAX GDP	24.77
ARMAX Lithium Batteries World Trends	20.84
ARMAX Mineral Resources	22.48
ARMAX(2,1,0) with errors	21.87

Forecasting Chile

Model	MAPE
Holt's exponential smoothing	26.68
ARIMA(1,1,0)	13.17
ARMAX SQM	13.29
ARMAX Lithium Batteries World Trends	14.31
ARMAX Mineral Resources	12.77
ARMAX(1,1,0) with errors	**13.39**

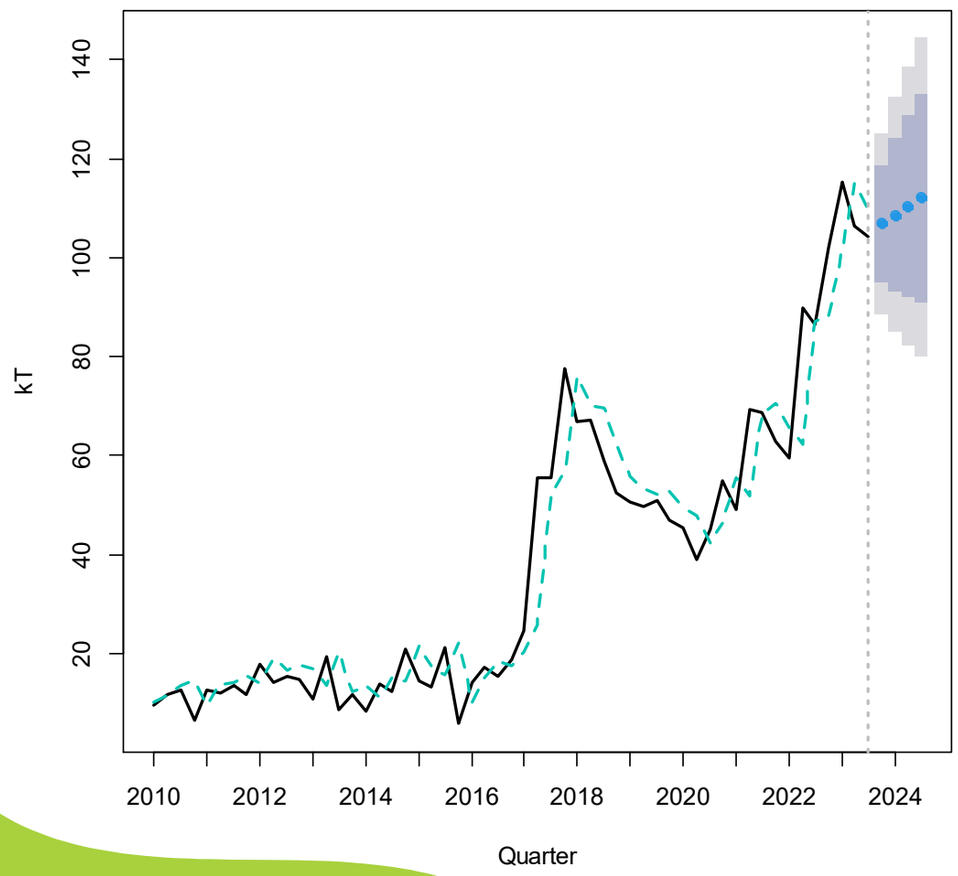
Forecasting Australia and Chile

Comments:

- In the case of Australia, Holt's Exponential Smoothing is the model with the best MAPE
- In the case of Chile, ARMAX with explanatory variables has a low MAPE
- Forecasting will depend on the forecasting of explanatory variables
- Exports of lithium are expected to have a moderate or increasing behaviour
- Mineral Resources stock seems to be an important variable for **both countries**
- In general, **stock prices** of main companies and **trends of Google** can help forecast Lithium demands

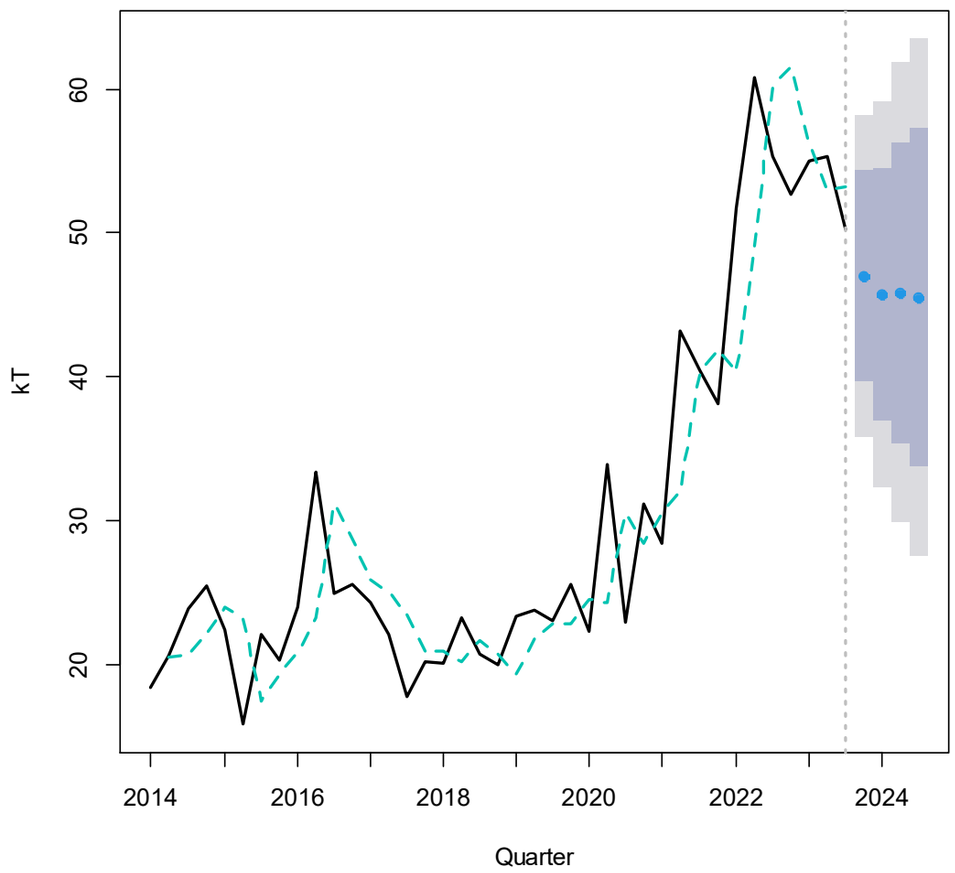
Forecasting Australia and Chile

Holt's Exponential Smoothing Australia



ARIMA(1,1,0) with errors Chile

SQM stock, Lithium trends, Mineral Resources stock



06

Future of Lithium

Expectations in the Lithium market for the future

Future of lithium

- Companies Albemarle and Tianqi, as well as the Australian Government through grants, are still investing in Western Australia for lithium extraction[1,2]
- Australia is facing competition from the “lithium triangle” of Chile, Bolivia, and Argentina[3]
- Chile’s state-owned copper mining company Codelco reached a deal with miner SQM to take a majority stake in a new partnership for future lithium projects in the country until 2060[4]

Albemarle’s lithium refinery plant, Australia

Latin America's Lithium Triangle

Source: [1]ABC News Australia, [2]Australian Resources and Investment Mining Journal, [3]The Guardian, [4]Financial Times

Padova, another player in the clean technology expansion race

Powering the Future in a Sustainable way: Lithium Analysis and Forecasting

Mario Tapia