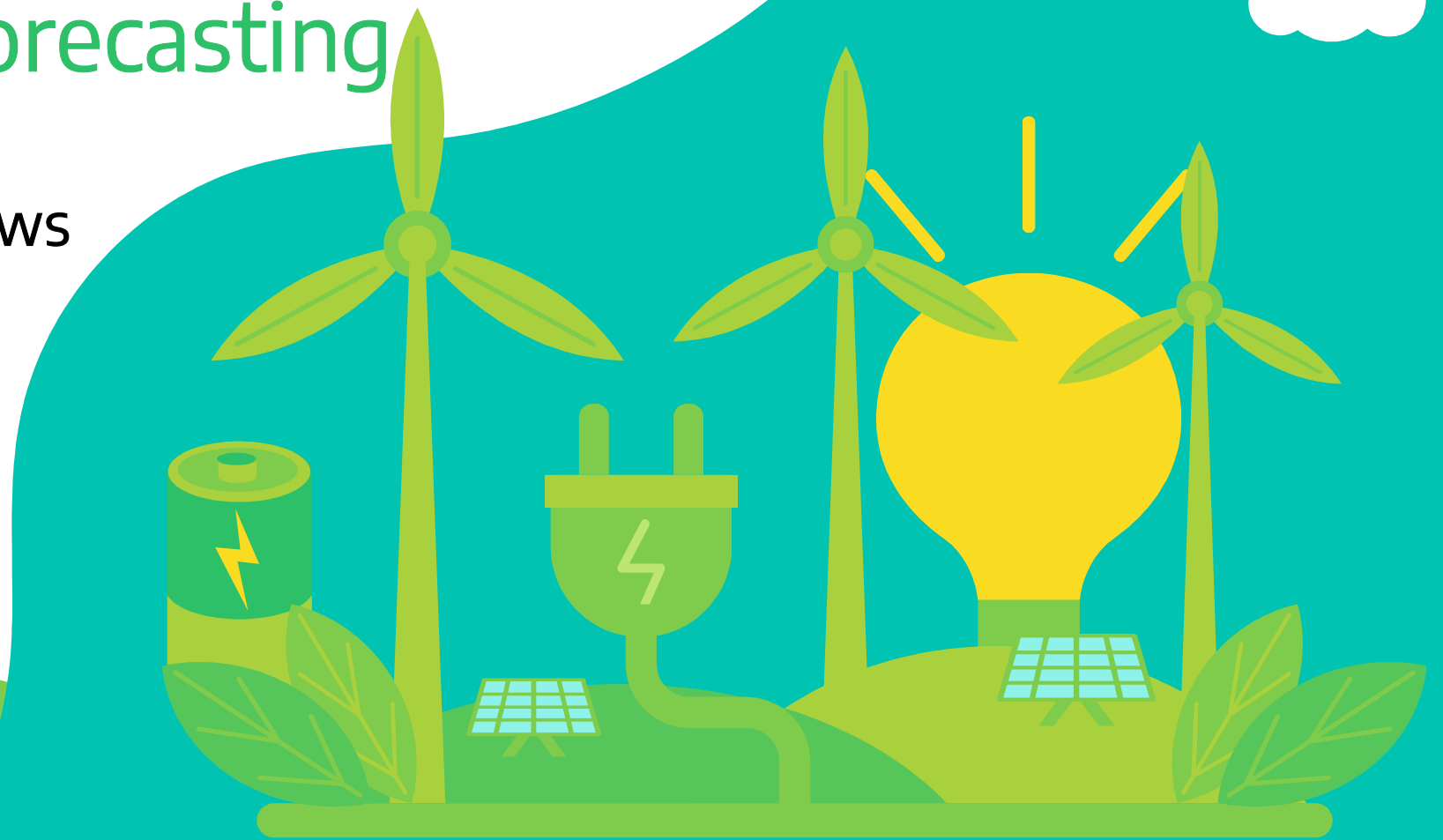


# Powering the Future in a Sustainable way: Lithium Analysis and Forecasting

Alejandra Cruces Andrews



# Program

01

## Lithium demand factors

Key aspects of the increasing demand of lithium worldwide

04

## Forecast

Holt's Exponential smoothing, KNN regression, ARIMA

02

## Lithium time series

Comparison of lithium exports in Chile and Australia

05

## Conclusions

Summary of the main findings

03

## Explainability analysis

Linear regression, Bass model, GBM, Competition model

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

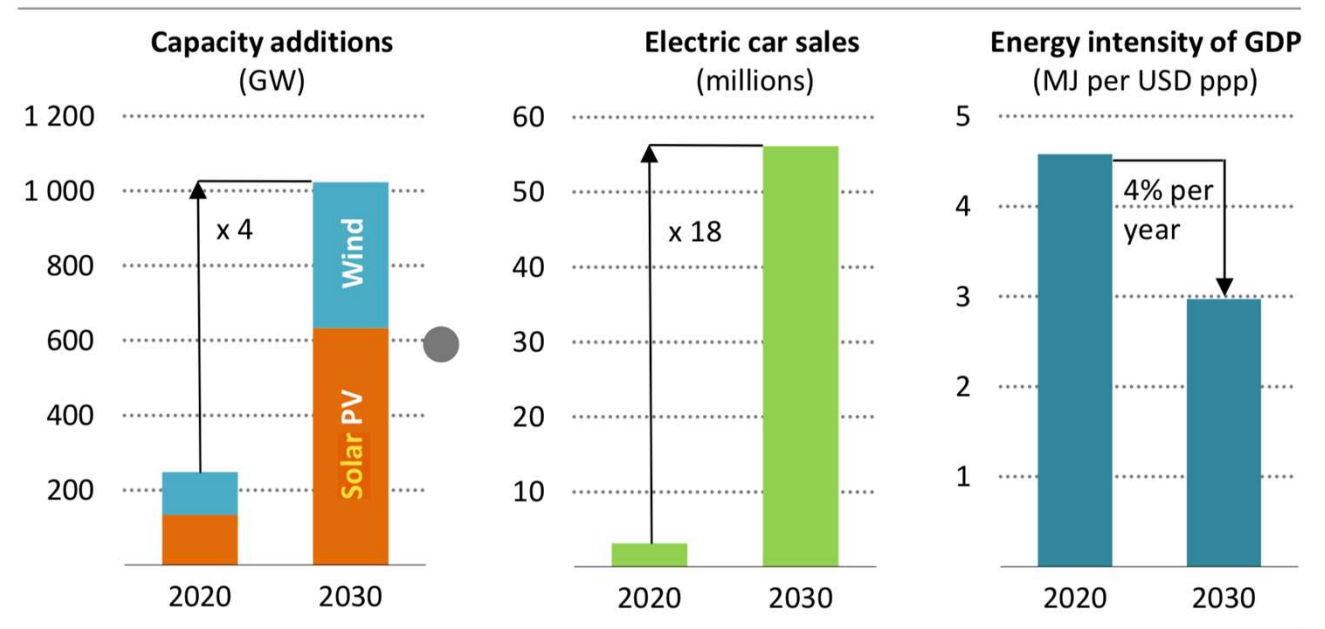
- To achieve global net-zero emissions by 2050 the conversion to electric transport is a cornerstone<sup>1</sup>



Source: <sup>1</sup>IEA (A Roadmap for the Global Energy Sector)

A clean technology expansion by 2030 is needed

#### Key clean technologies ramp up by 2030 in the net zero pathway



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](#)



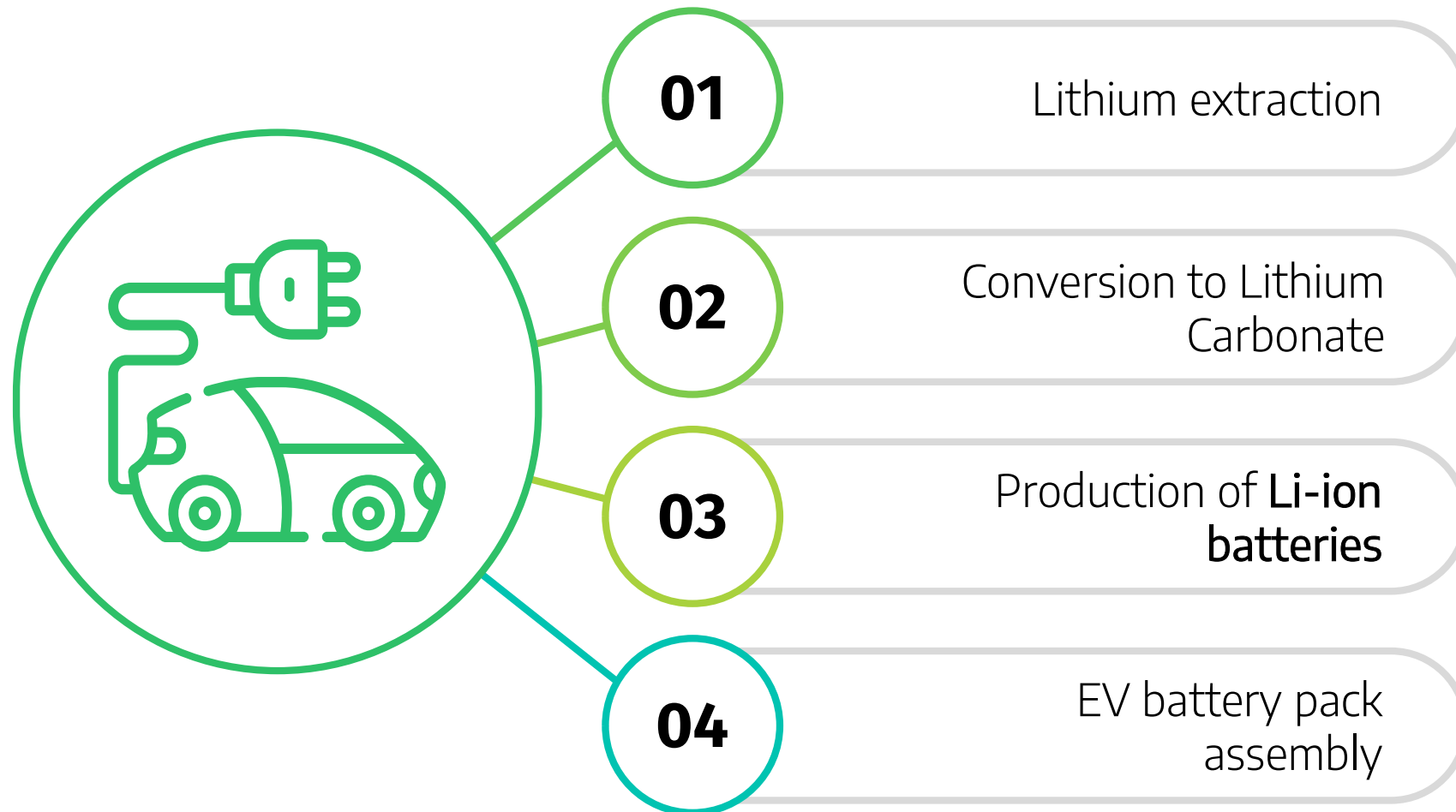
## Sales of **electric vehicles** surge as fast-charging sites double across **Australia** in a year

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





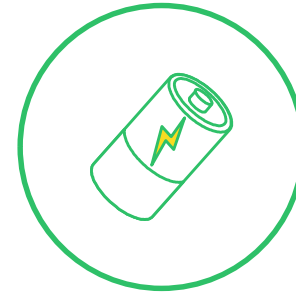
# What is Lithium?



Chemical  
Element



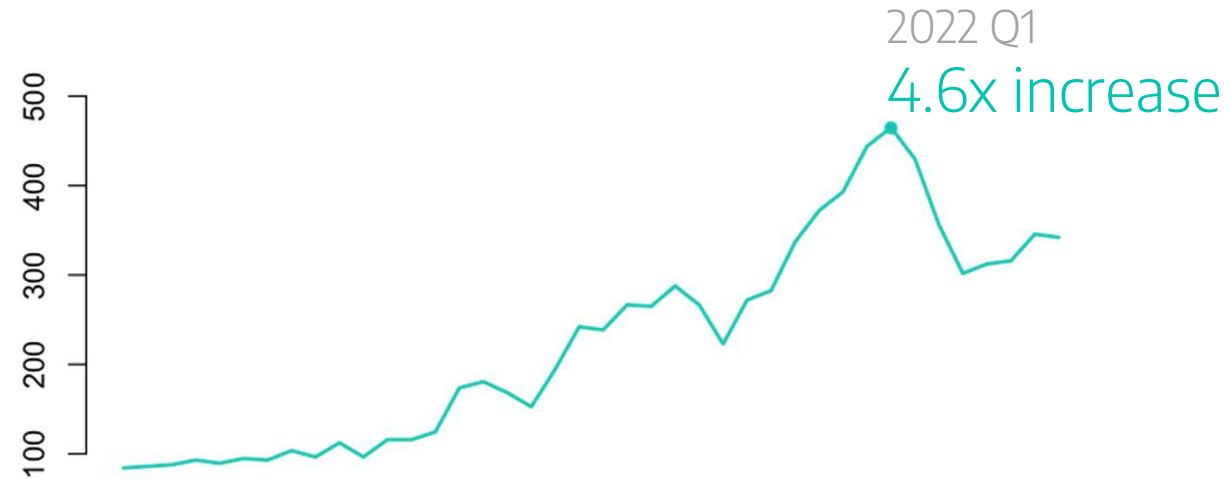
Abundant  
Element



Crucial for  
Batteries

# Google Trends Interest over time

Electric vehicles



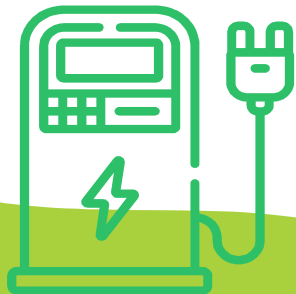
Lithium



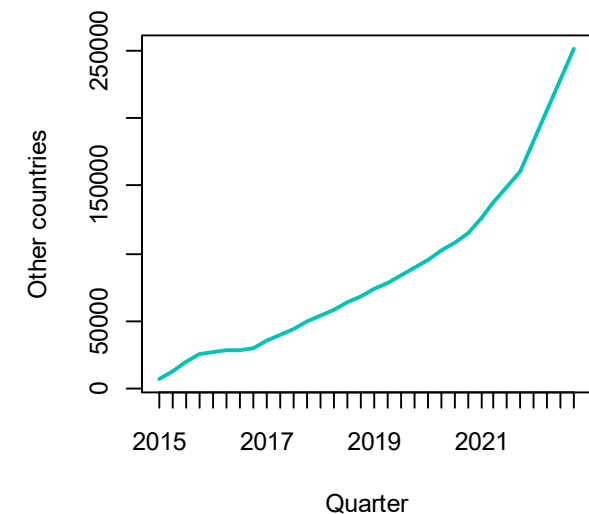
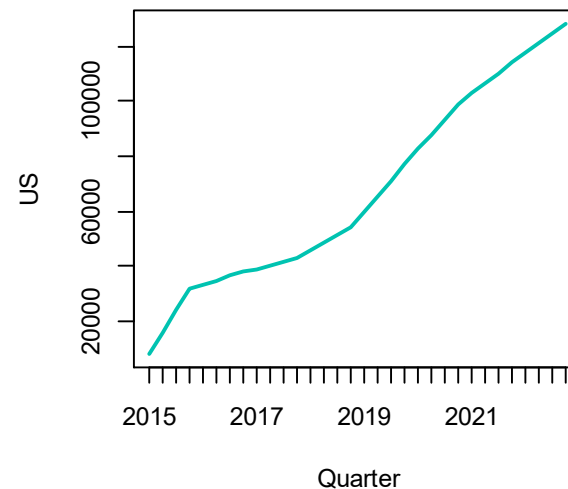
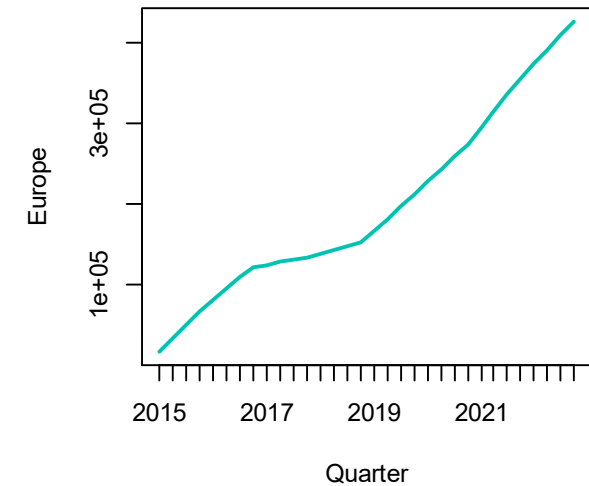
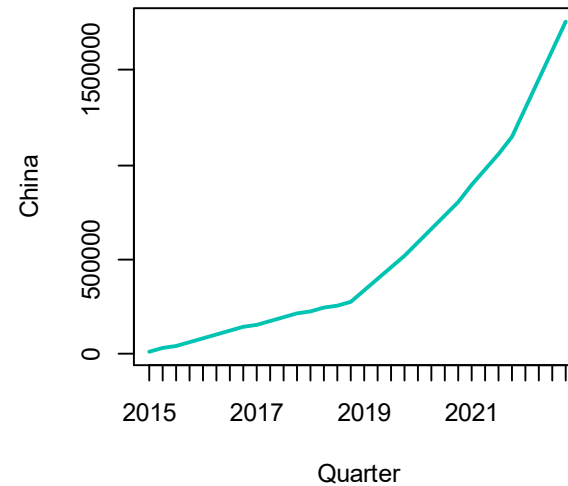
Source: Google Trends

# 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<sup>1</sup> and slow<sup>2</sup> electric chargers available

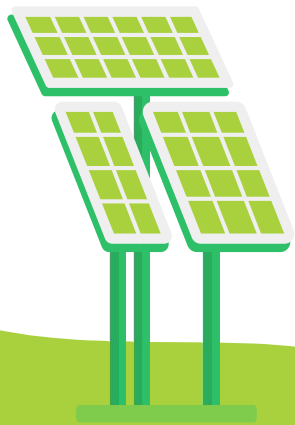


Source: <sup>1</sup>IEA (fast chargers),  
<sup>2</sup>IEA (slow chargers)

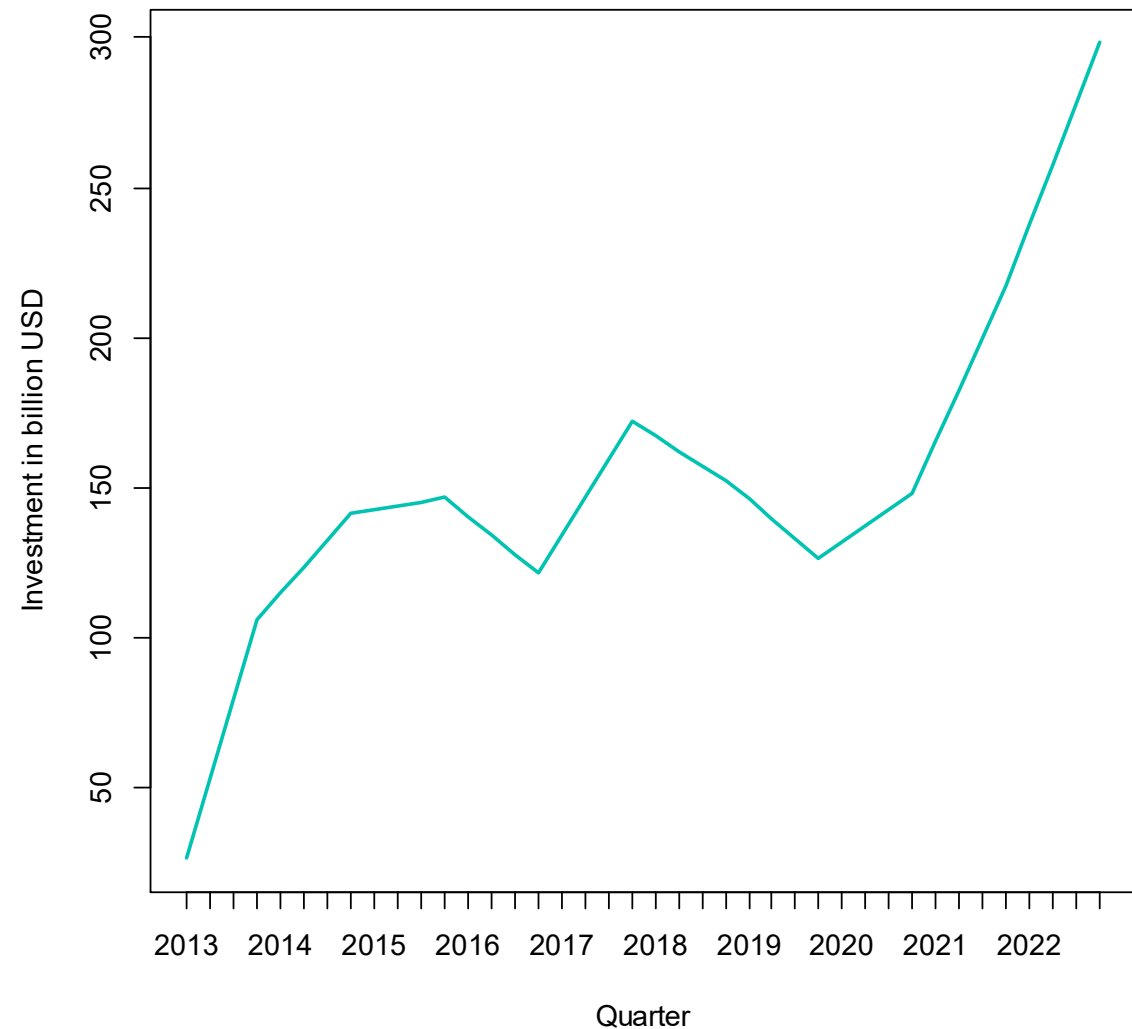


# Solar investment Billion USD

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



Source: Statista





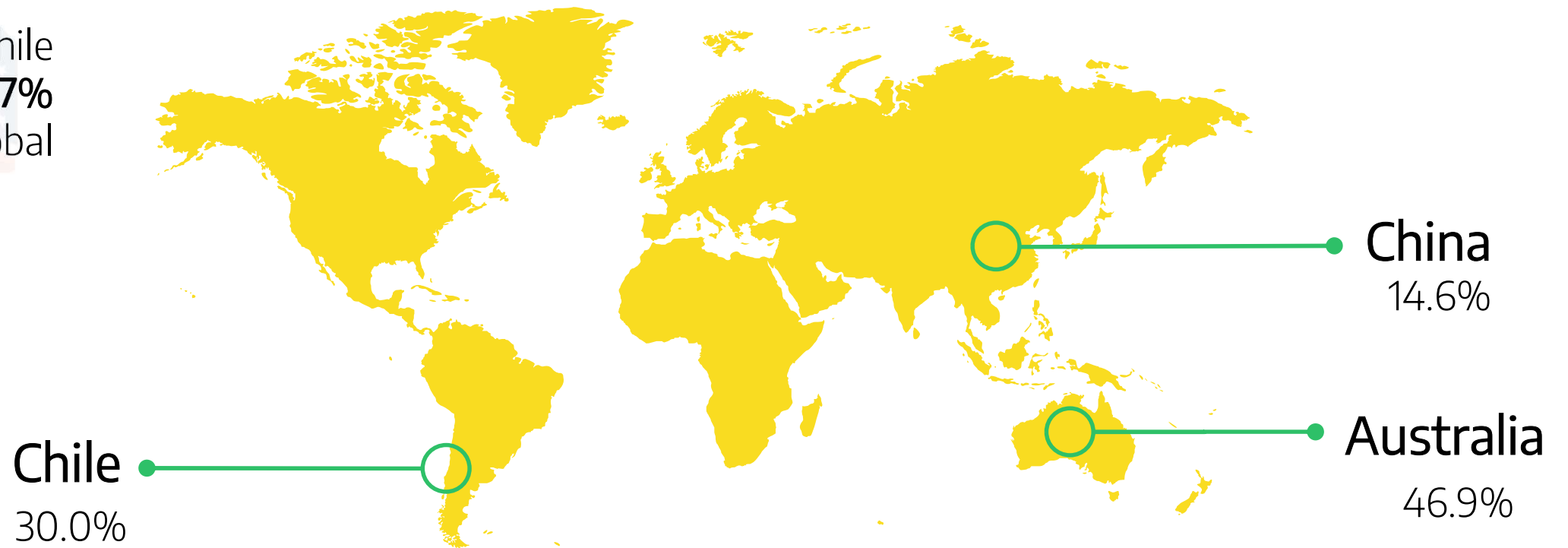
02

# 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

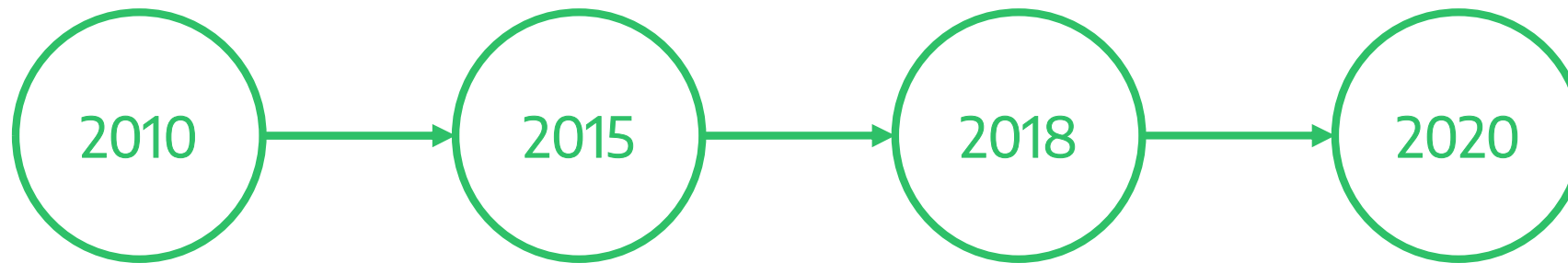
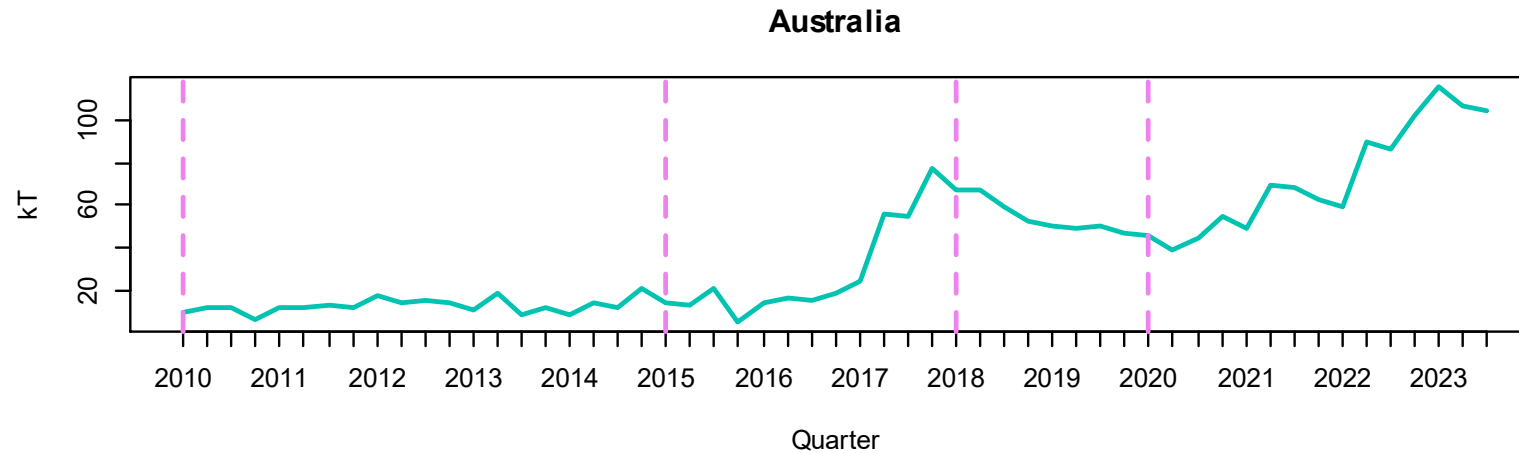
- Significant rise from 2016 to 2018
- Decline from 2018 to 2020
- Recovery from 2020 onwards
- Most of Australia's exports go to China



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



# Lithium Australia events



China began granting subsidies to EV buyers<sup>1</sup>

China's government announced that it would phase out subsidies progressively from 2016 and by the end of 2020<sup>2</sup>

Excess of supply, slower demand growth for EV, criteria to qualify for subsidies became more stringent in China<sup>3</sup>

China's government extended the subsidies by two years to the end of 2022, due to the pandemic and the economic downturn<sup>4</sup>



## Sources:

<sup>1</sup> [China's National Development and Reform Commission](#)

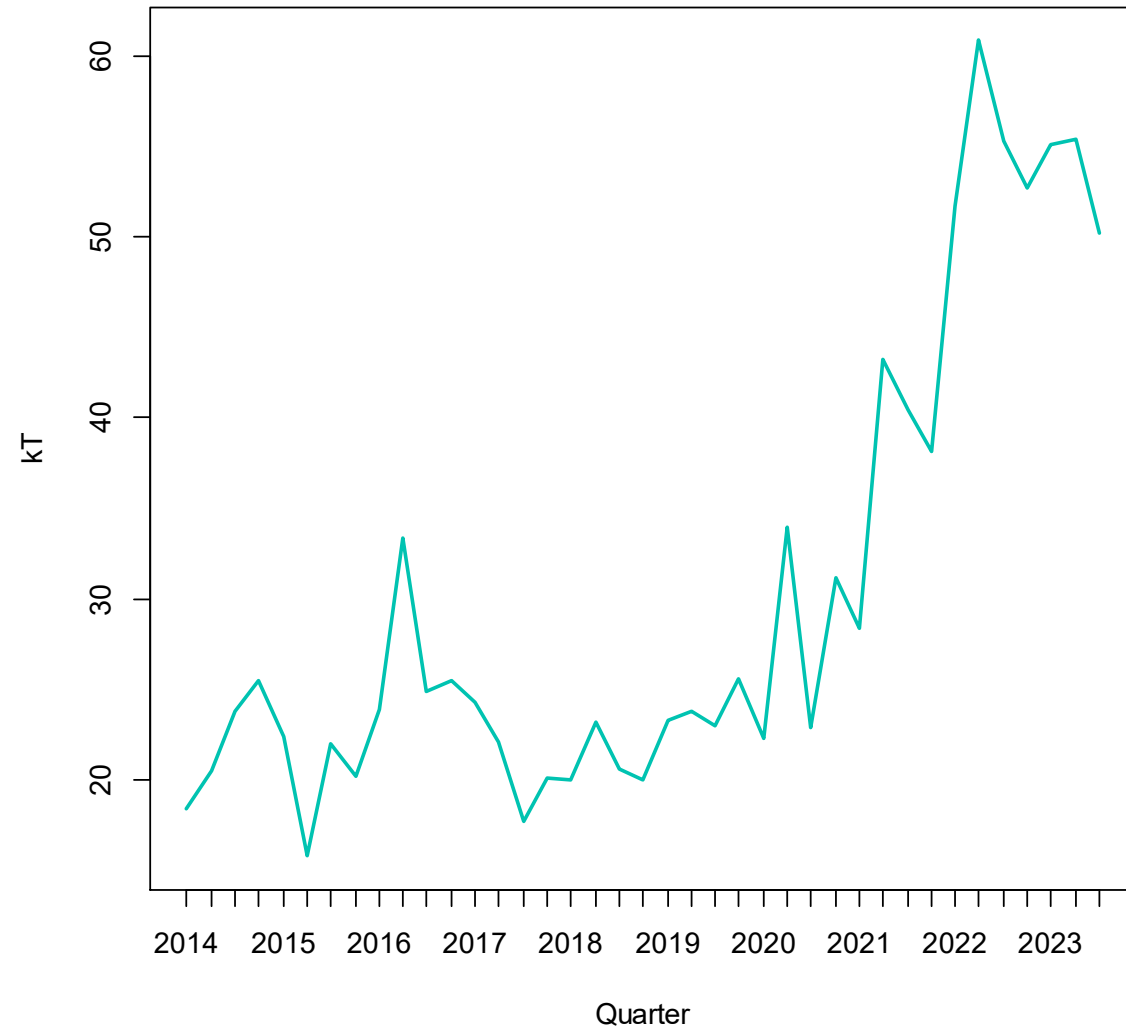
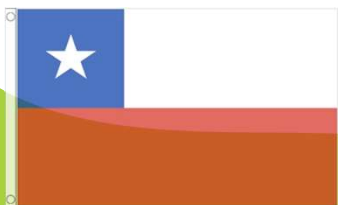
<sup>2</sup> [International Council on Clean Transportation](#)

<sup>3</sup> [Reuters news agency](#)

<sup>4</sup> [Ministry of Finance of the People's Republic of China](#)

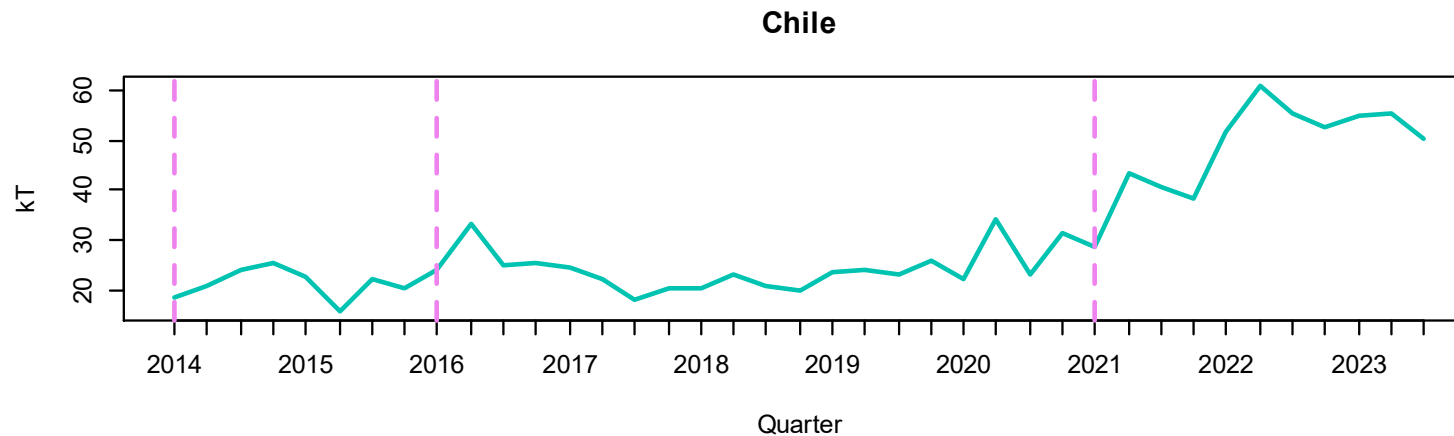
# Lithium exports Chile

- 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



Decree: National Lithium Commission in 2014

Chile experienced a decrease in its lithium production and market share<sup>1</sup>

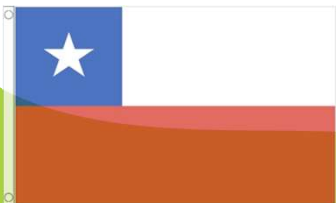
In the first five months of 2021, Chile increased significantly the exportation of lithium carbonates (China, Japan, South Korea)<sup>2</sup>. Most of Chile's exports go to China<sup>3</sup>

Sources:

<sup>1</sup> [Mining.com](https://www.mining.com)

<sup>2</sup> [Reuters news agency](https://www.reuters.com)

<sup>3</sup> [World Integrated Trade Solution](https://www.worldintegratedtrade.com)



# Lithium exports Australia and Chile

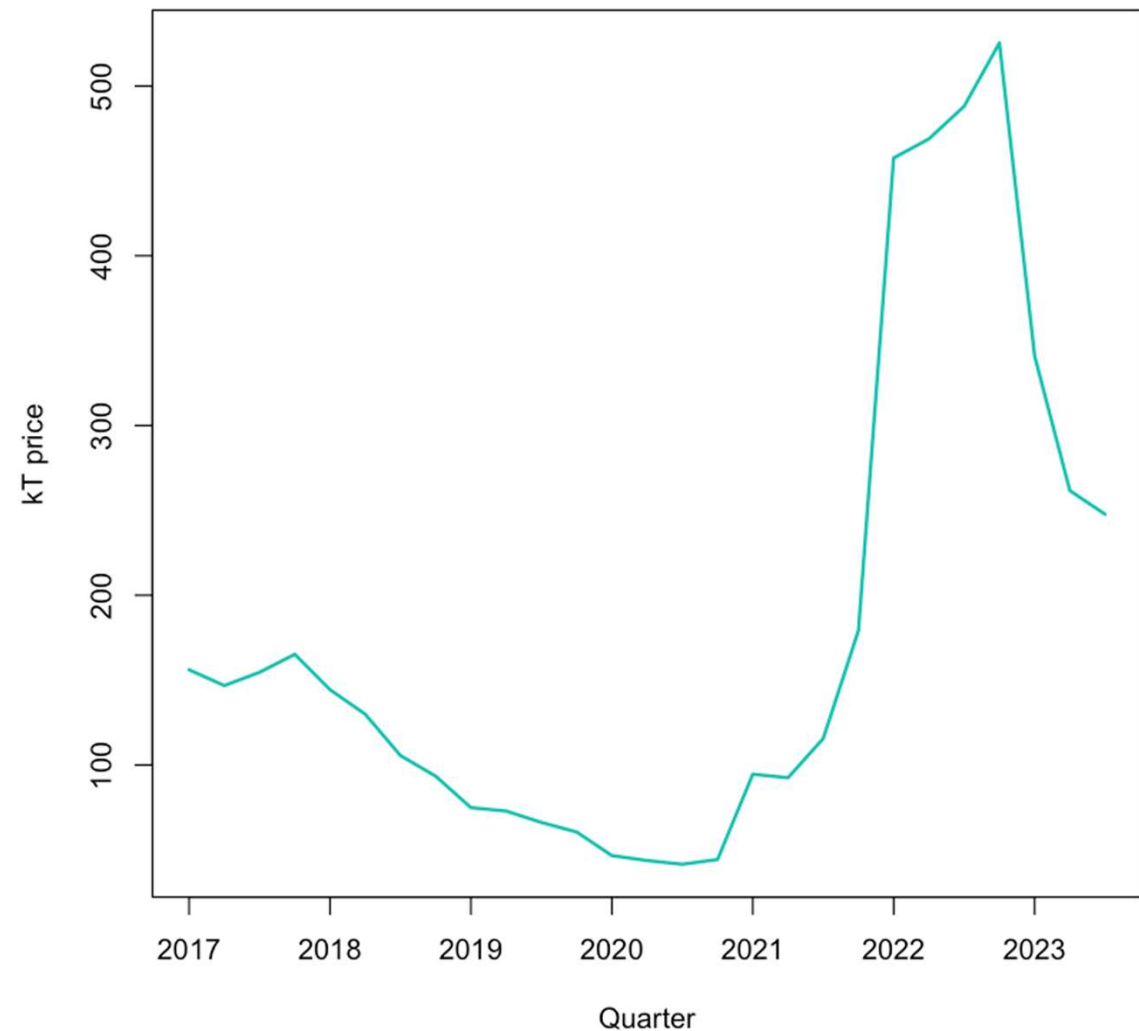
- Australia has a larger experience in Lithium extraction and exploration
- Both countries have experienced an increase in their exportations since 2020.
- Mainly explained by the growing interest in this product



# Lithium Carbonate Price per kilotonne (CNY)

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

Spot price

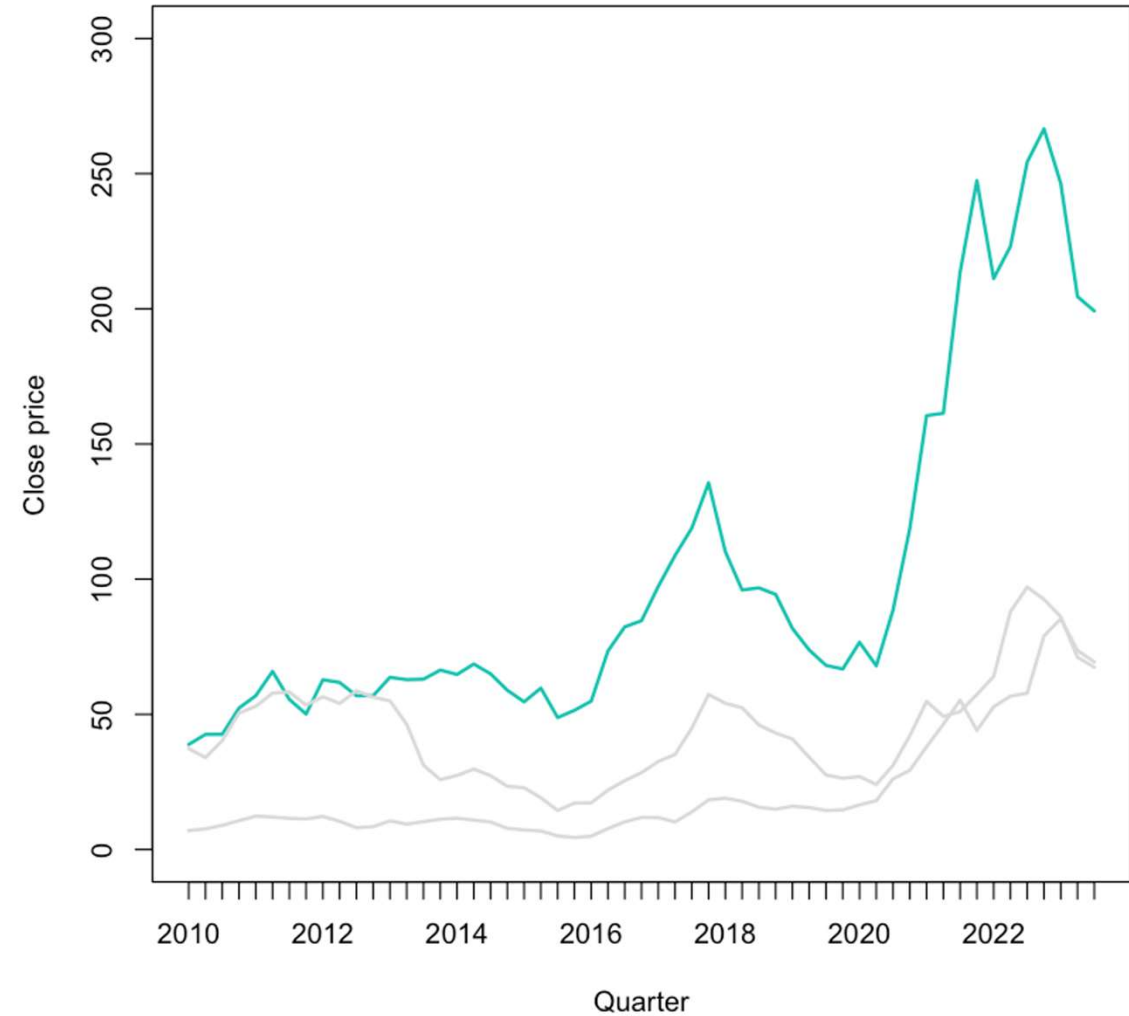


Source: Investing

# Stock Prices Lithium Companies

## Albemarle Corporation

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

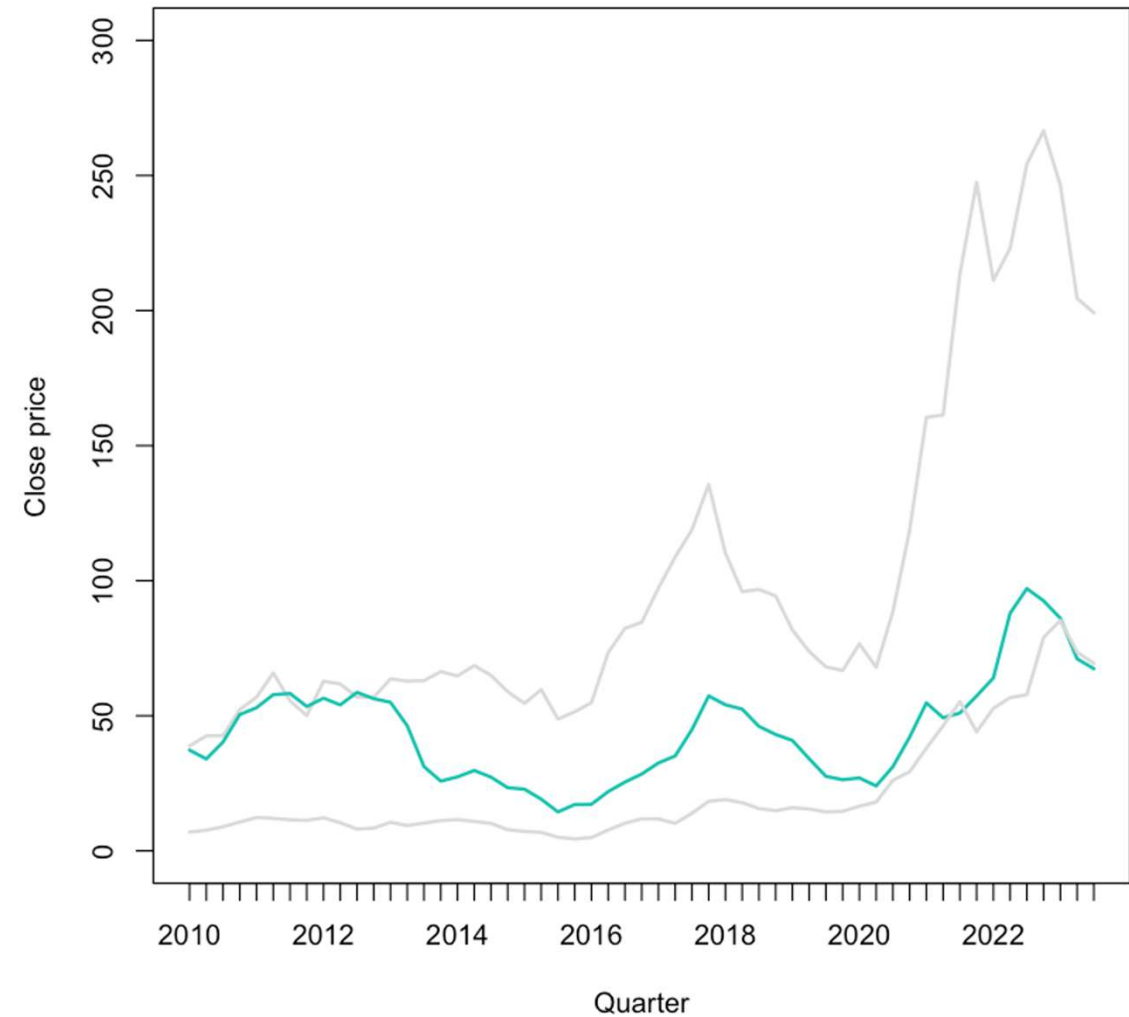


Source: Yahoo! Finance

# Stock Prices Lithium Companies

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

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

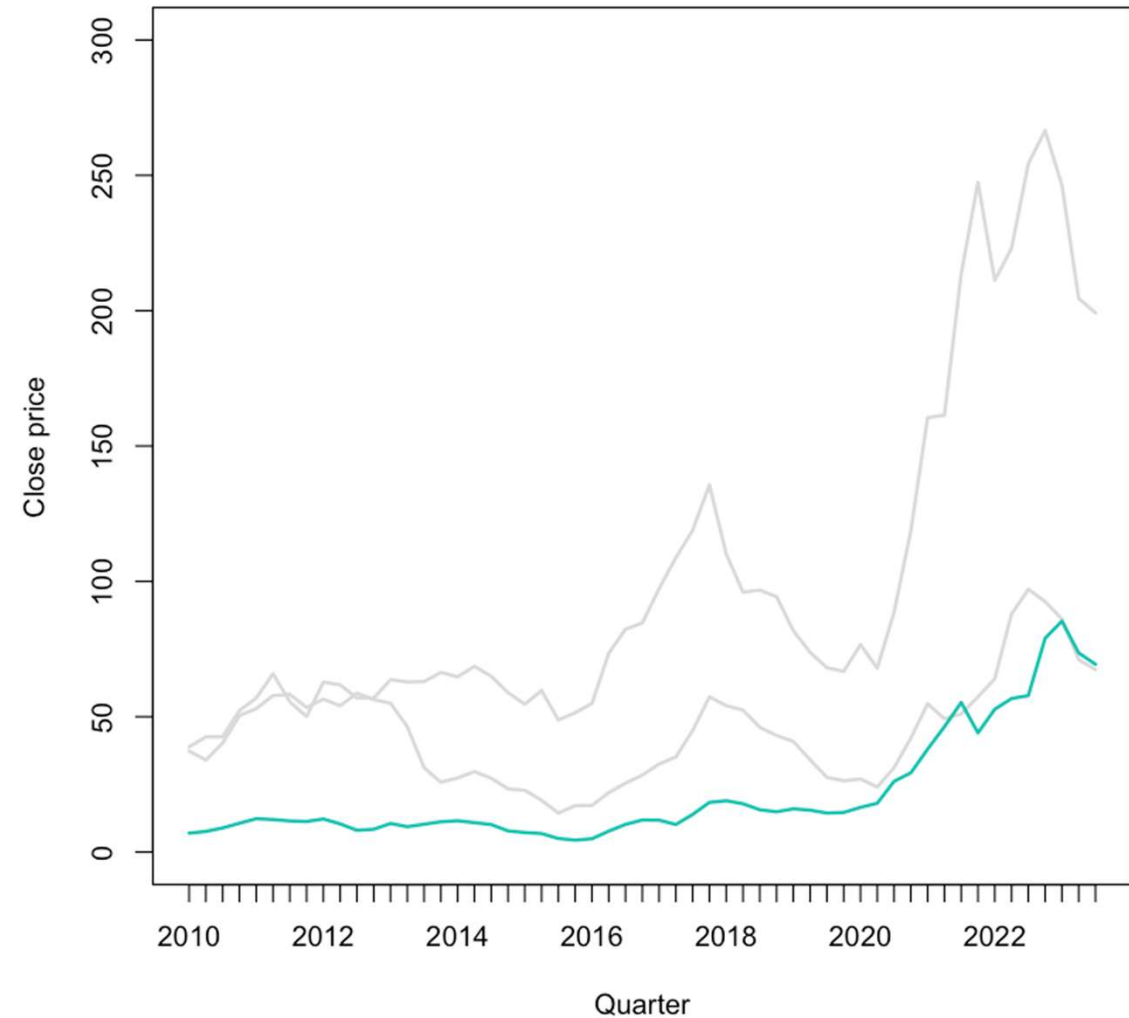


Source: Yahoo! Finance

# Stock Prices Lithium Companies

## Mineral Resources Limited

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



Source: Yahoo! Finance





03

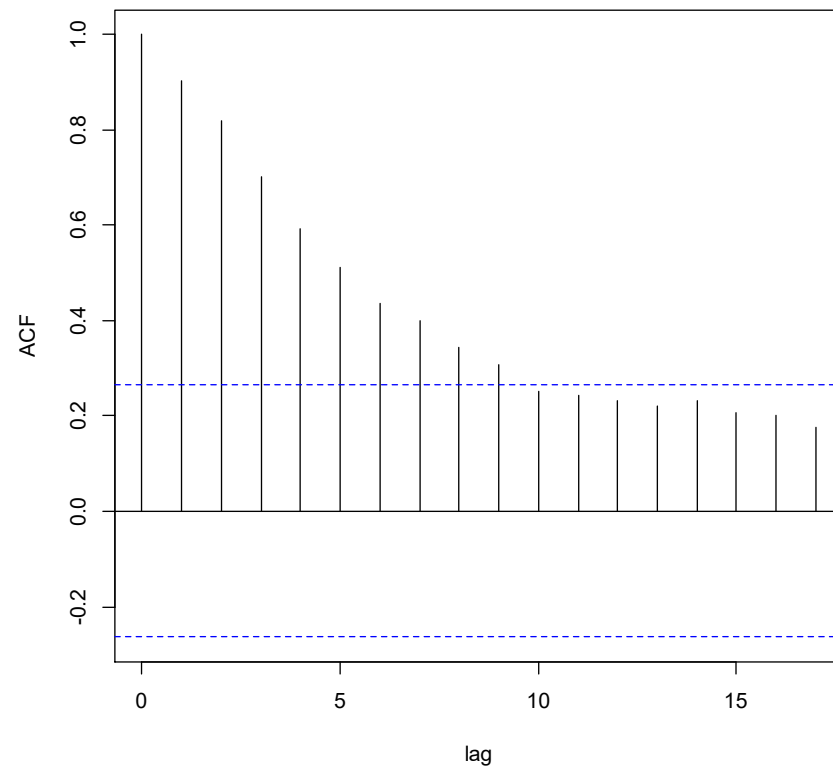
# Explainability Analysis

Linear Regression, Bass model, GBM, Competition model

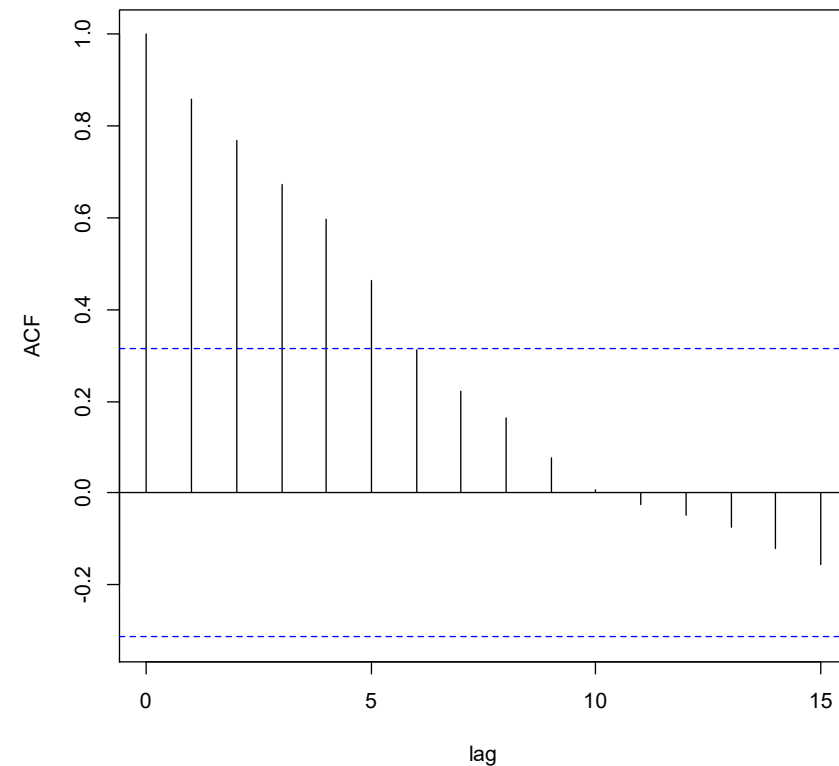


# Lithium time series Australia and Chile

## Australia



## Chile



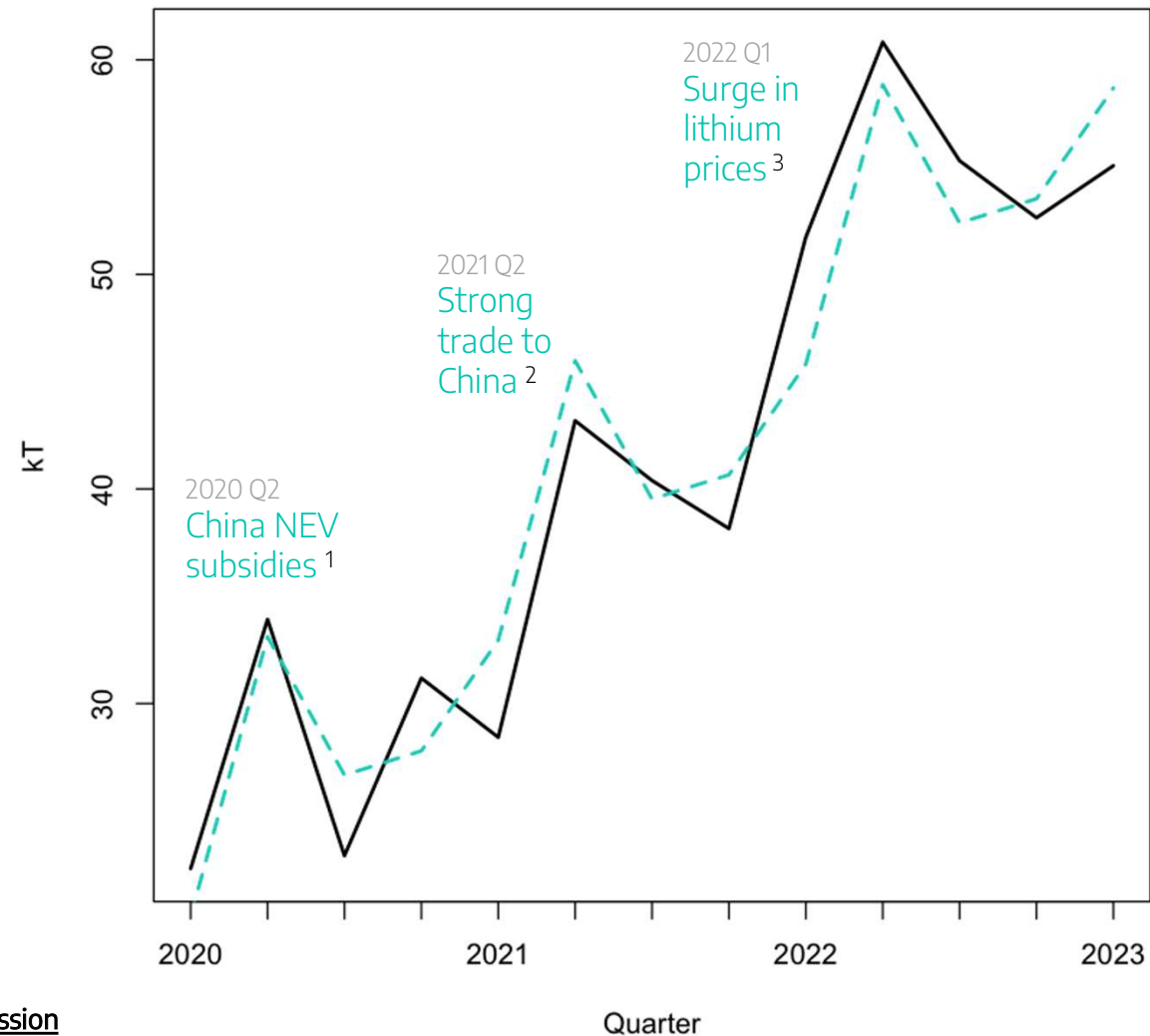
- Both cases: Trend is significant and Seasonality not significant (Linear Regression + season + trend) but...

# Linear Regression Window from 2020 onwards

## Chile

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

LR with seasonality factor (from 2020 Q1 - 2023 Q3)



### Sources:

<sup>1</sup> China's National Development and Reform Commission

<sup>2</sup> S & P

<sup>3</sup> S & P

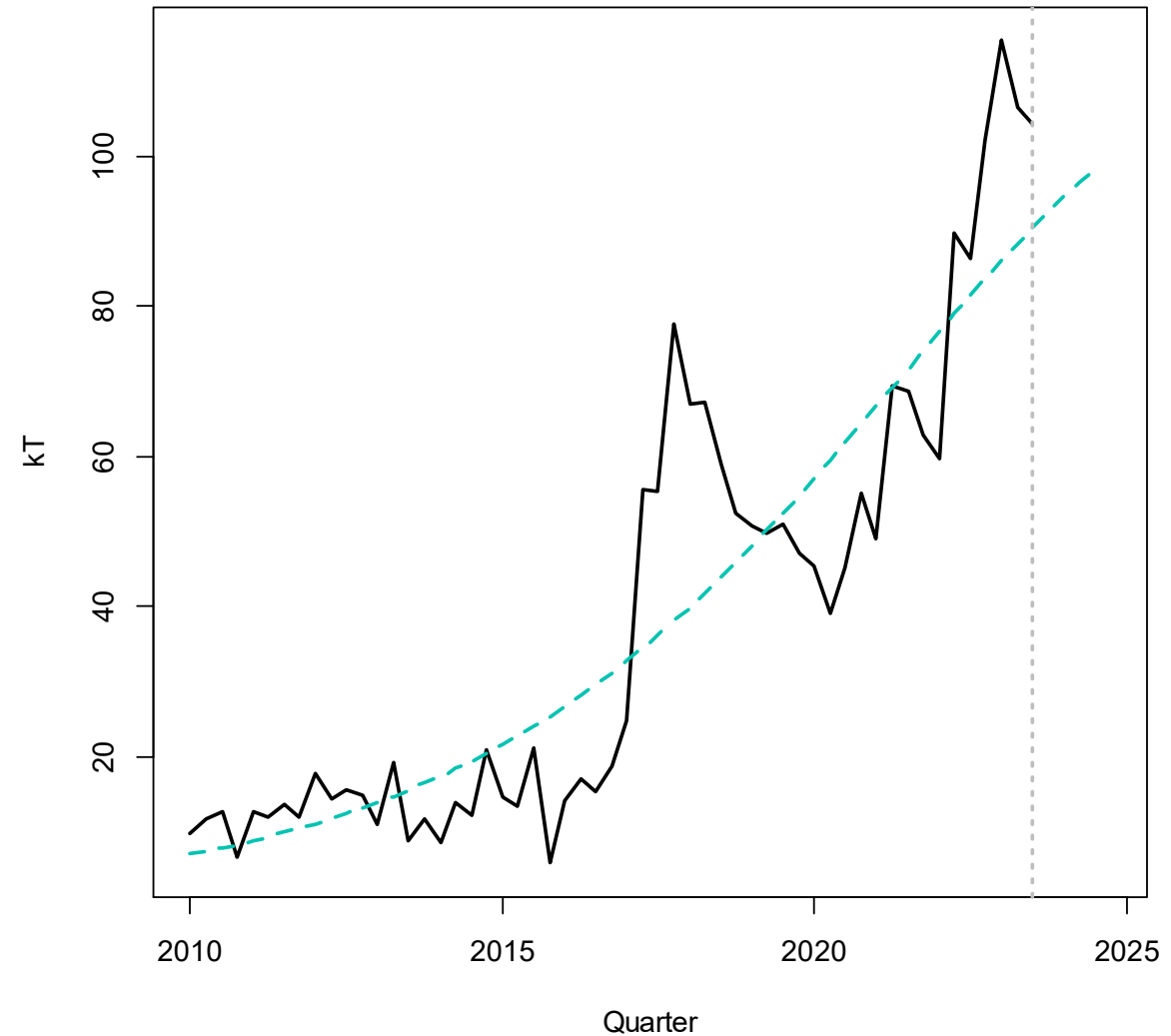
# Bass model Australia

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

Market Potential	Innovation	Imitation	R <sup>2</sup>
6.99e+03**	9.7e-04***	5.9e-02***	0.99



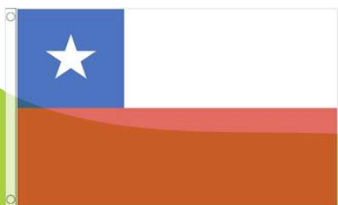
Instantaneous



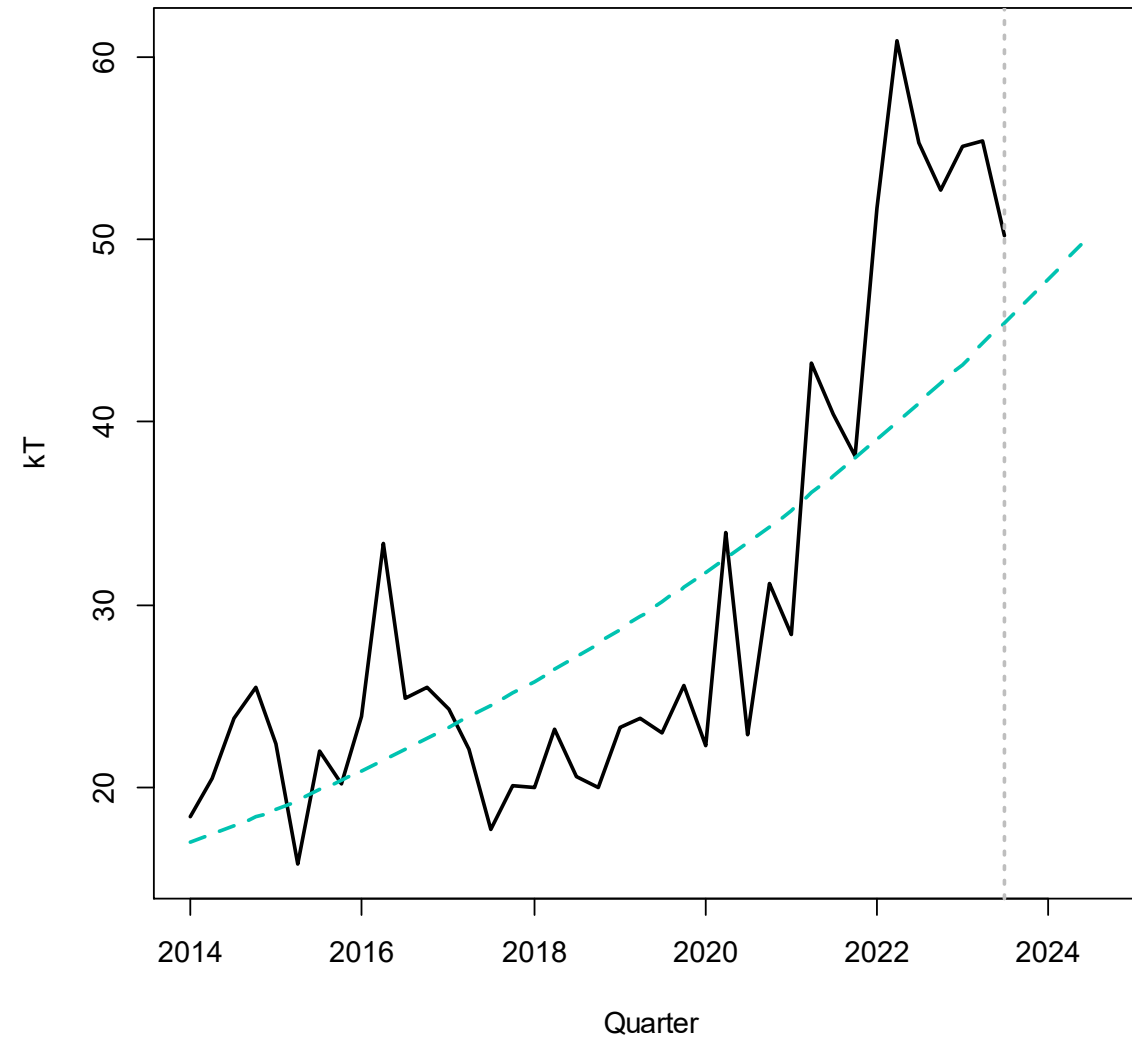
# Bass model Chile

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

Market Potential	Innovation	Imitation	R <sup>2</sup>
5.67+04	2.9-04	2.66-02	0.99



Instantaneous

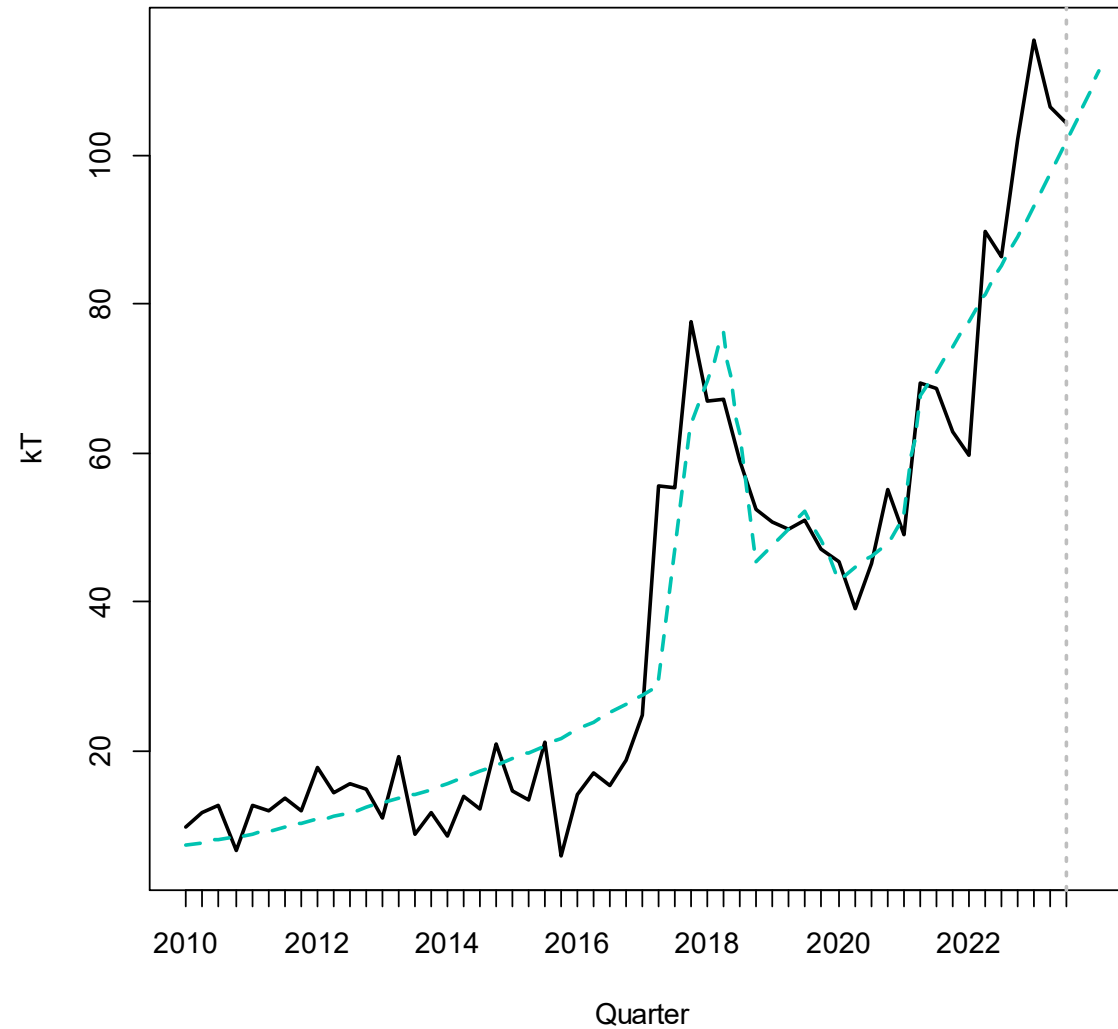


# GBM Australia

- 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



Instantaneous

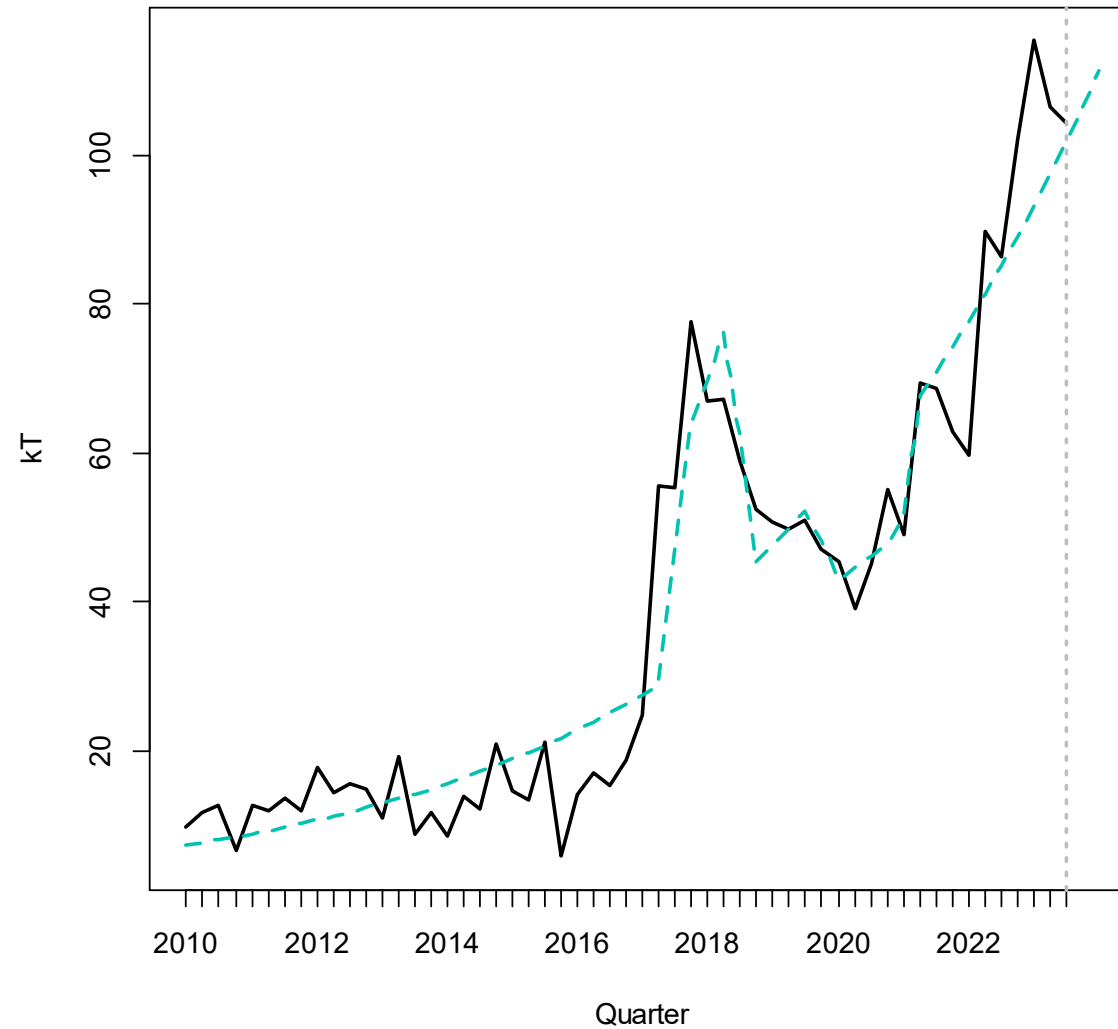


# GBM Australia

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

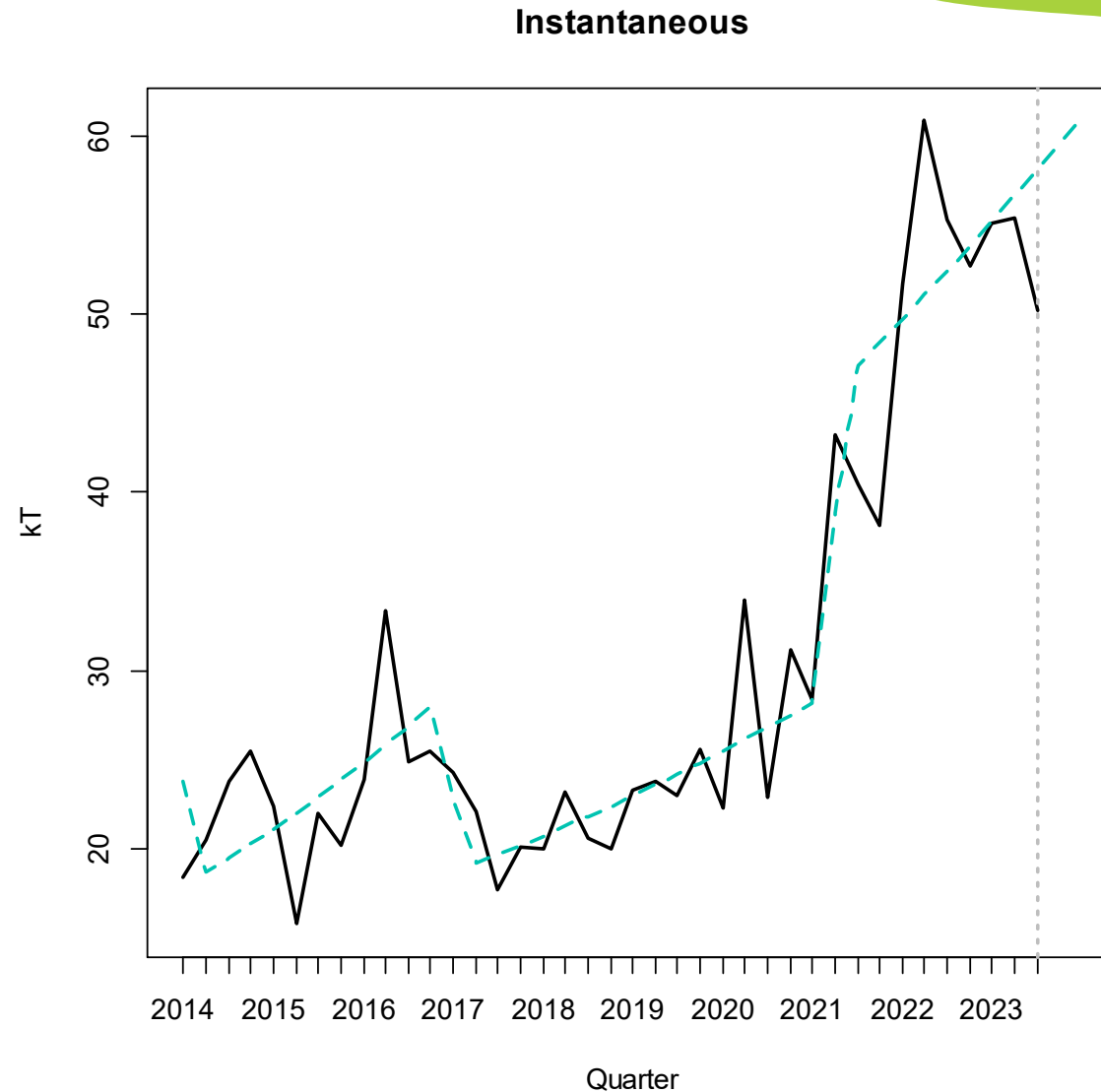
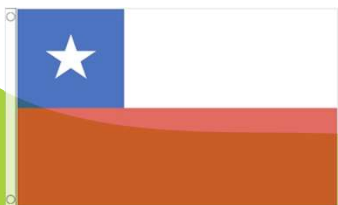


Instantaneous



# GBM Chile

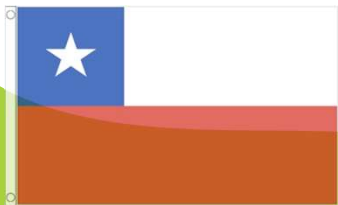
- Mixed shock at **2016.Q4** (rectangular), and **2021.Q1** (exponential)
- These periods could be approximately explained with the decrease in lithium production and market share of 2016, and the increase in exportations to China, Japan, and South Korea from 2021 onwards



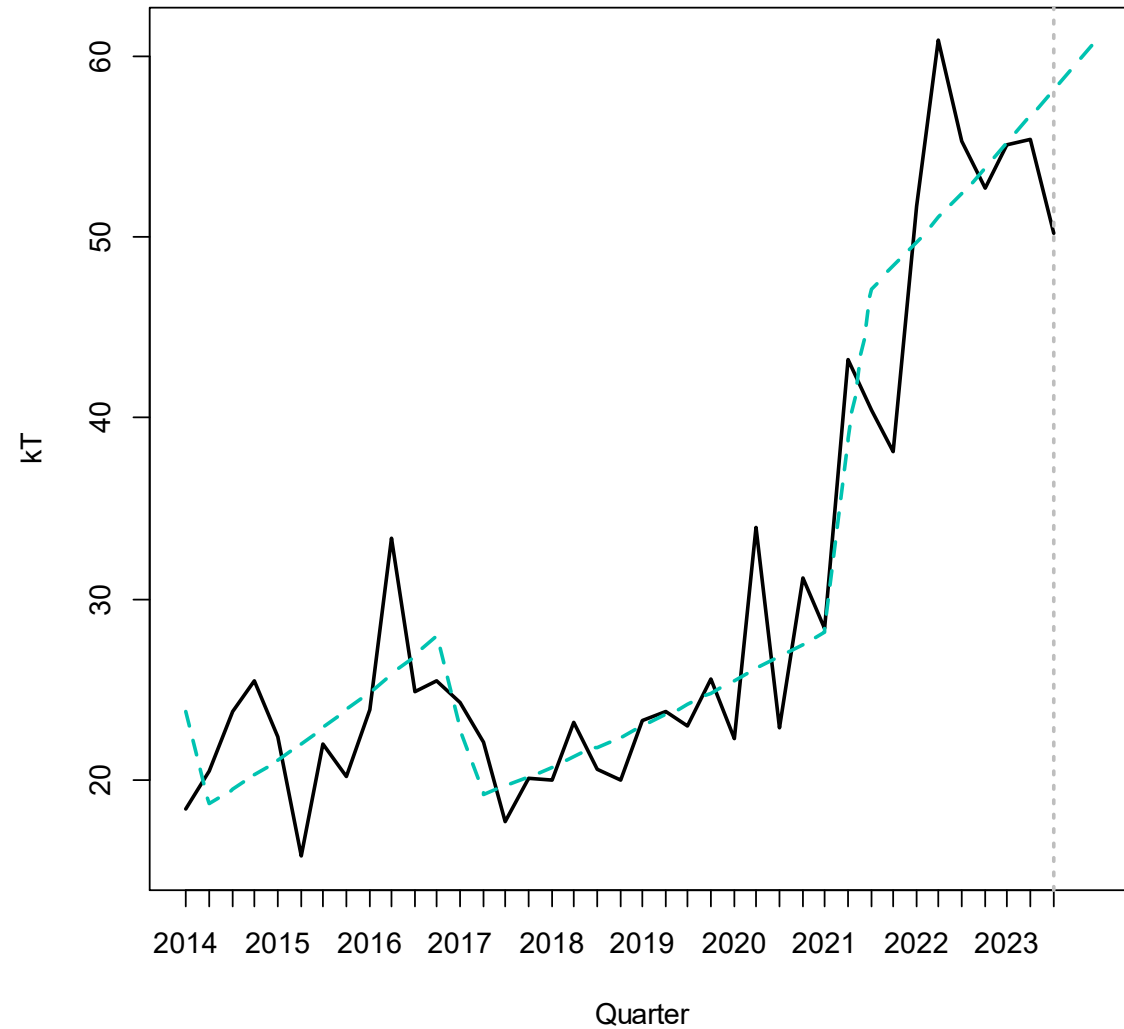


# GBM Chile

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



Instantaneous

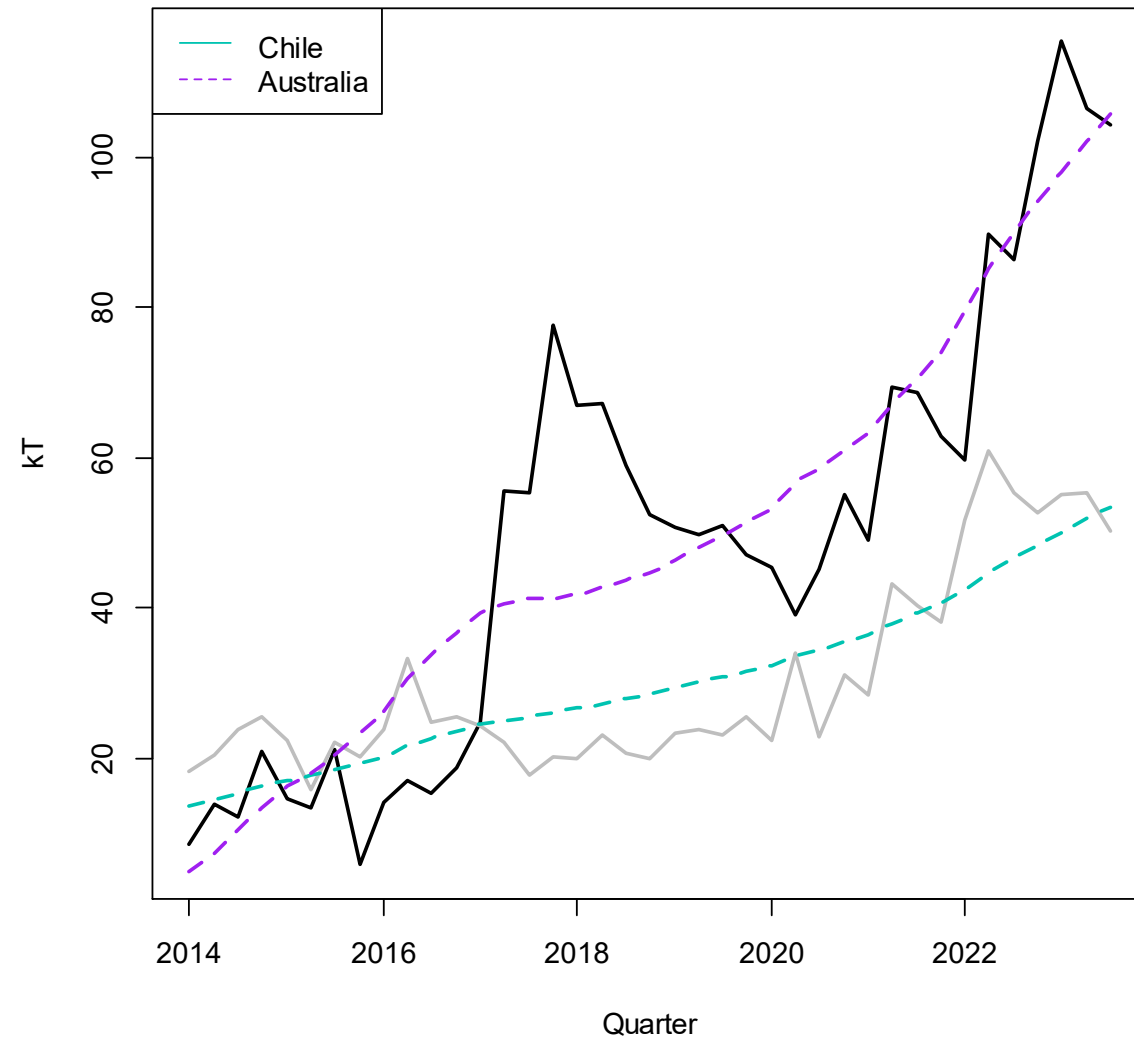


# Competition model Australia vs. Chile

- 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 <sup>2</sup>
1.47e-01**	-4.2e-03	0.83

Exports - Instantaneous





04

# Forecast

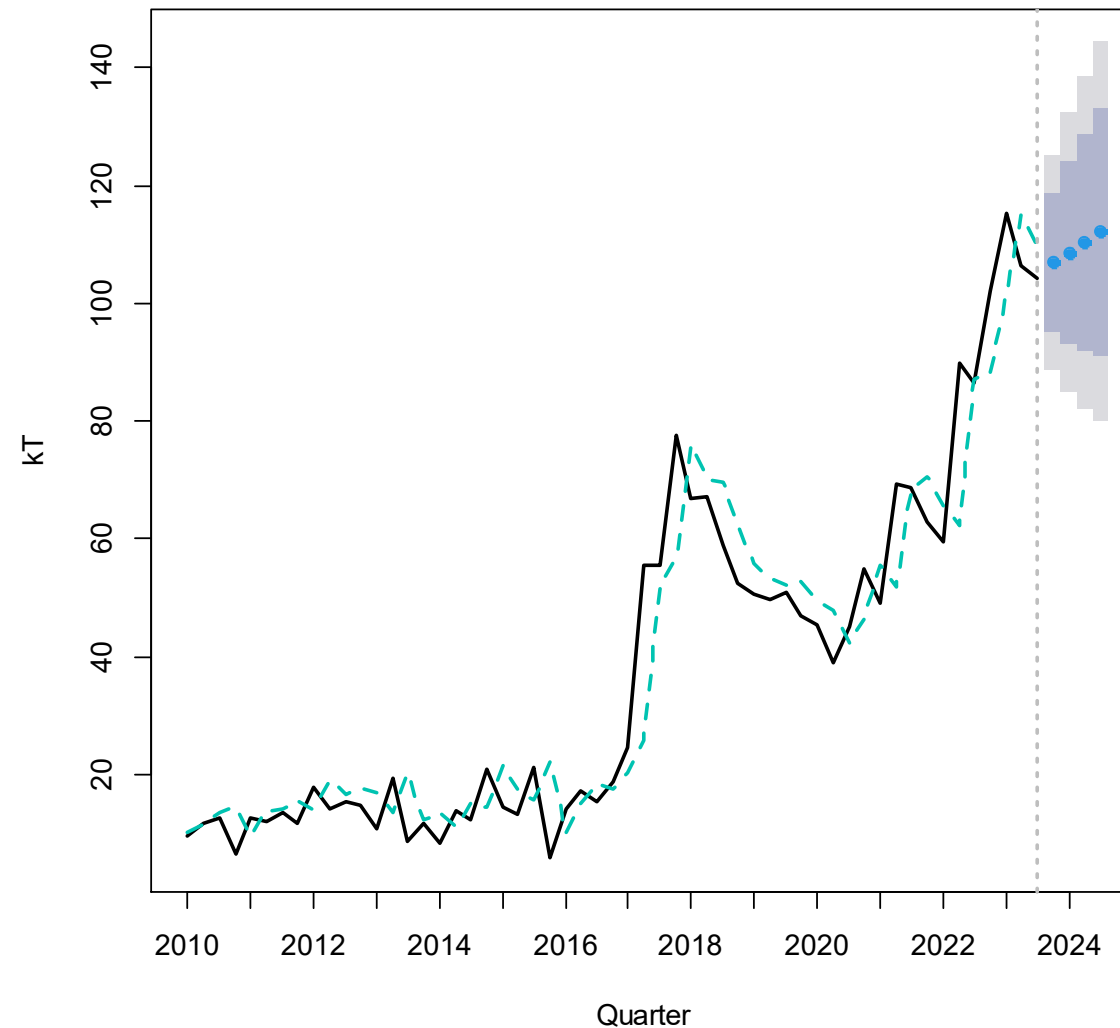
Holt's exponential smoothing, KNN regression, ARIMA



# Holt's exponential smoothing Australia

Comments:

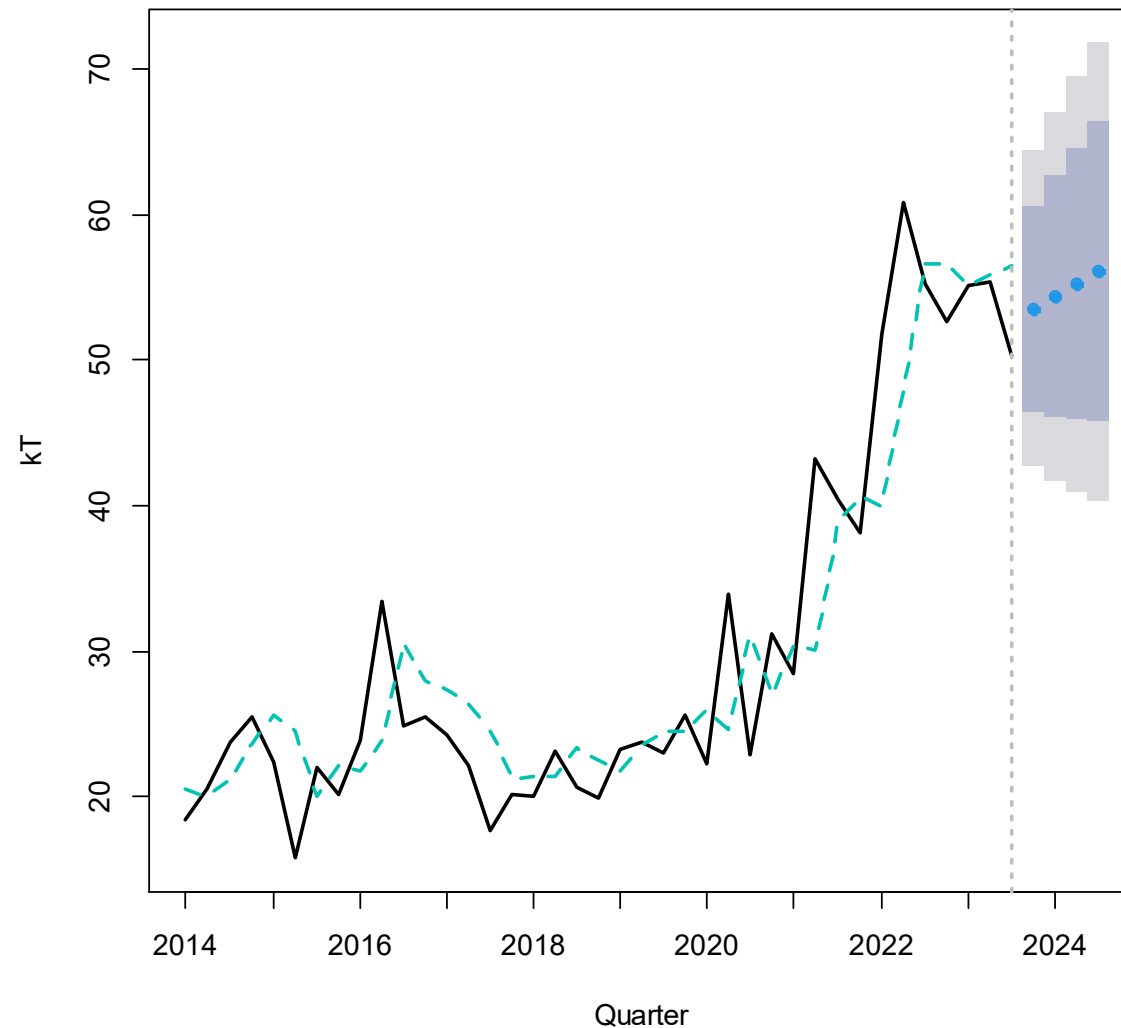
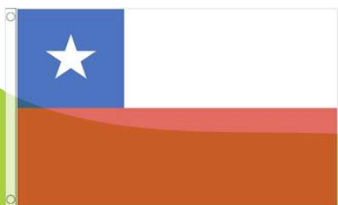
- Smoothing parameter chosen automatically (0.61)
- A time shift is observed
- Holt-Winters does not offer a better solution to this



# 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

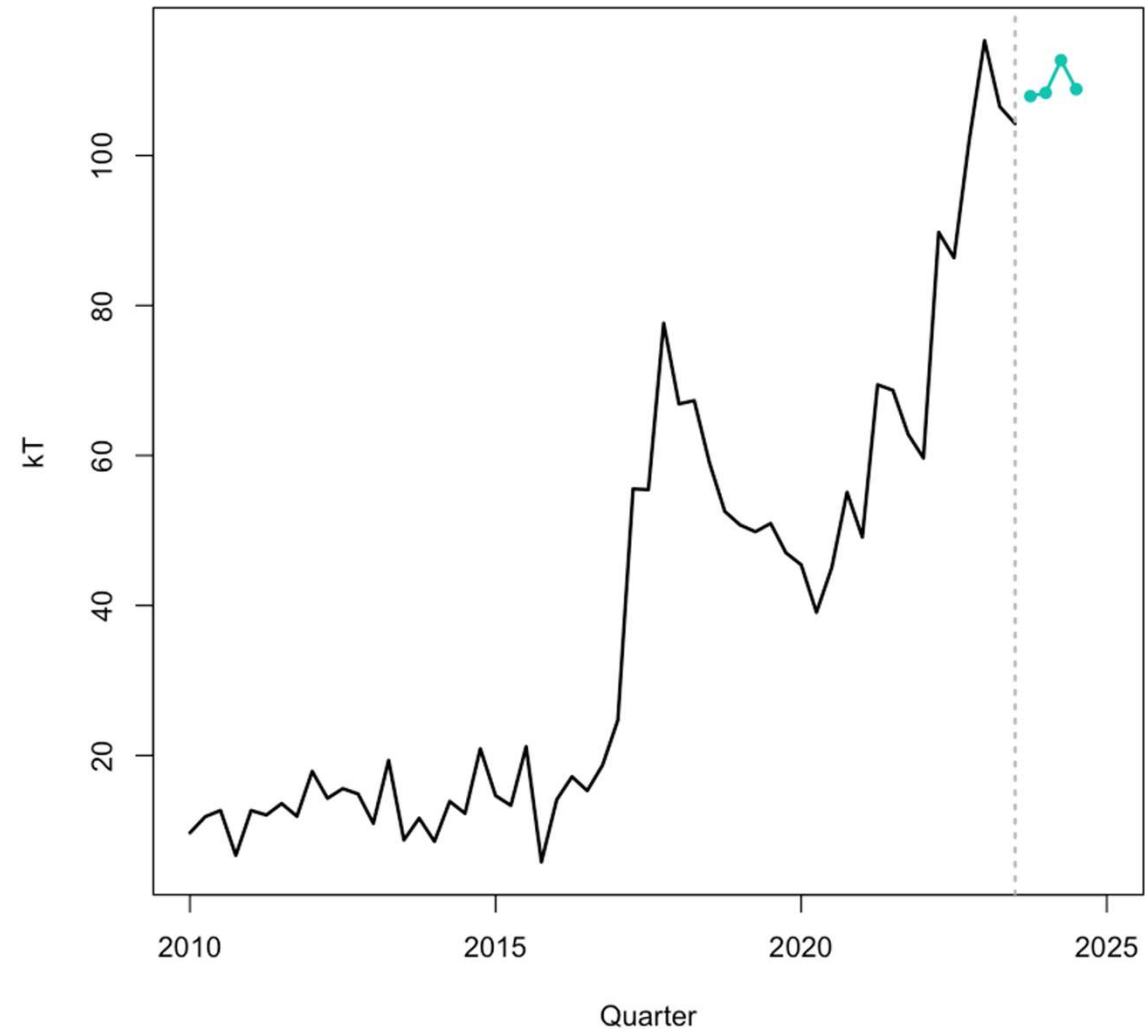
Comments:

- KNN adapted to time series using lagged values of the dependent variable<sup>1</sup>.
- $k = 2$
- Recursive strategy for forecast
- Exports to be tightly balanced according to forecast



Source: CRAN

1-Year Forecast for Australia exports



# KNN Regression Chile

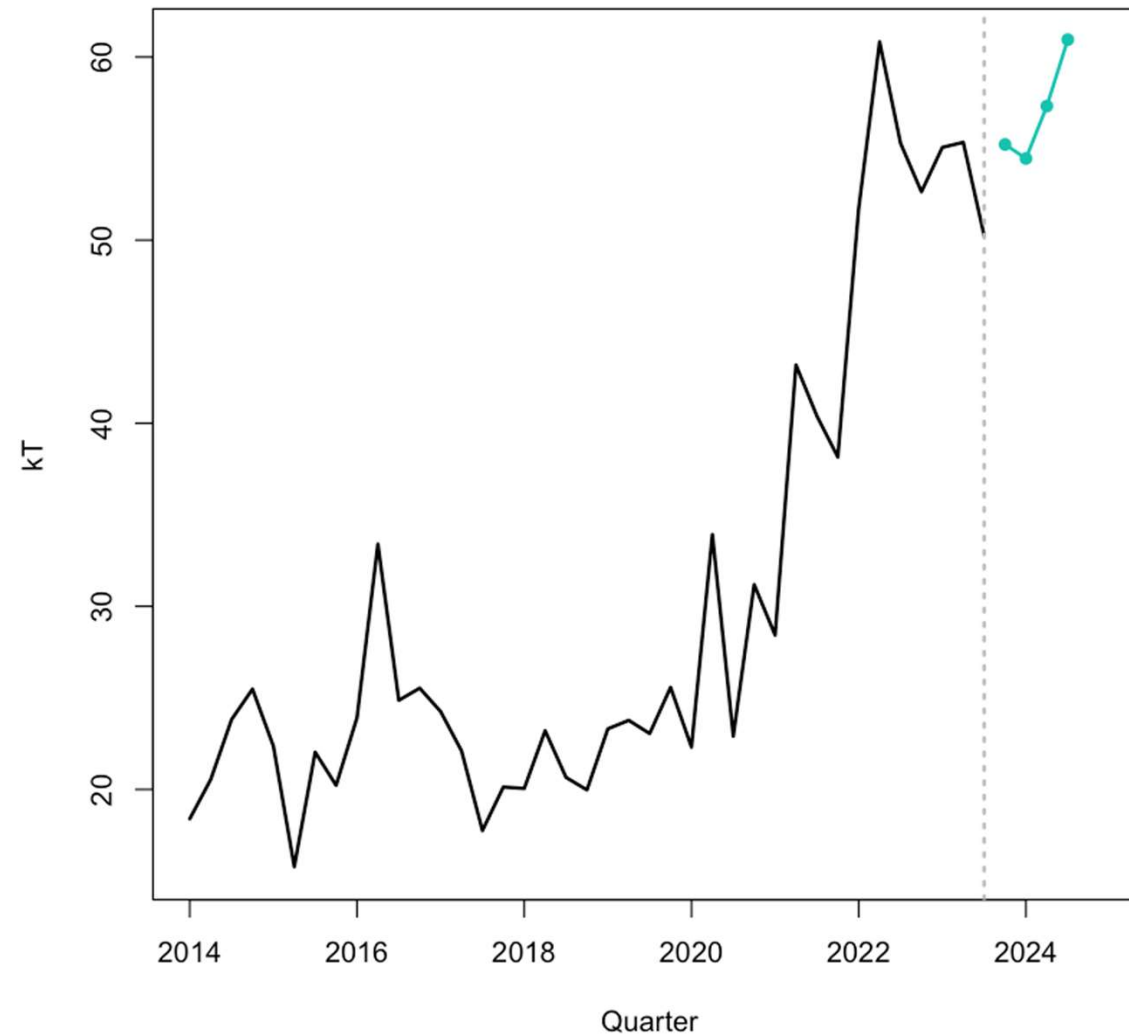
Comments:

- KNN adapted to time series using lagged values of the dependent variable<sup>1</sup>.
- $k = 2$
- Recursive strategy for forecast
- Optimistic forecast



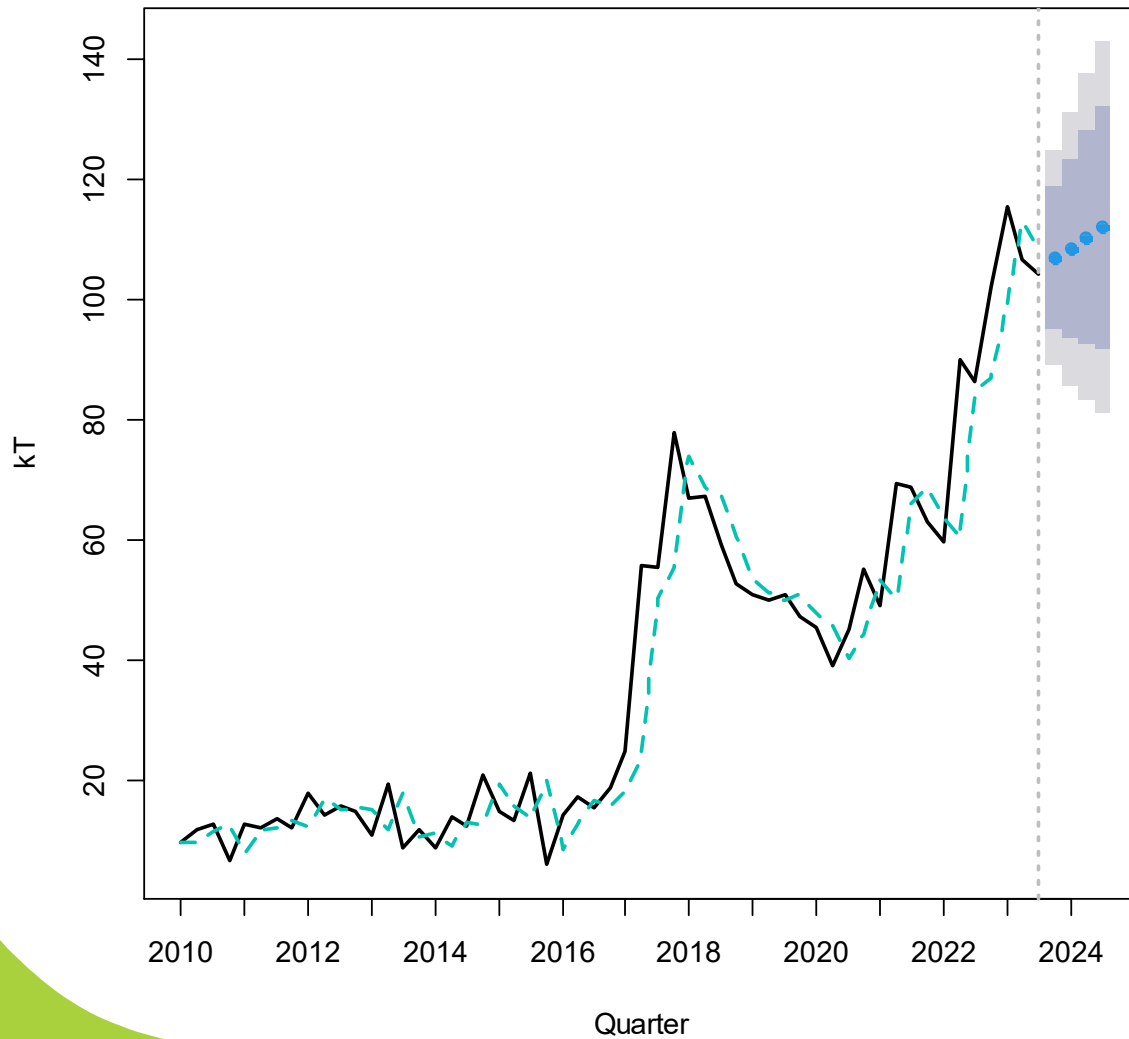
Source: CRAN

1-Year Forecast for Chile exports

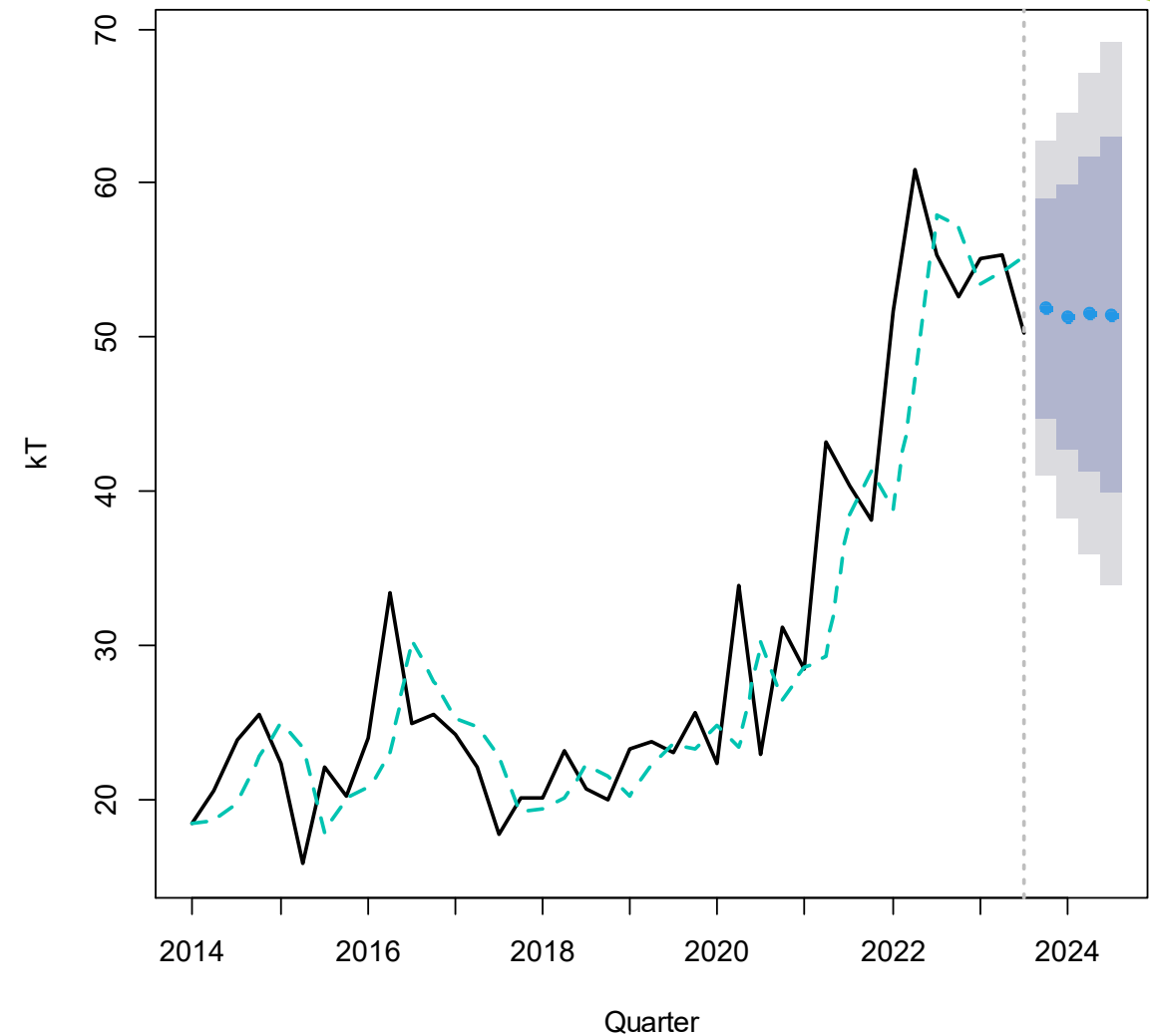


# ARIMA Australia and Chile

Australia ARIMA (1,1,0) with drift



Chile ARIMA (1,1,0) with drift





# 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

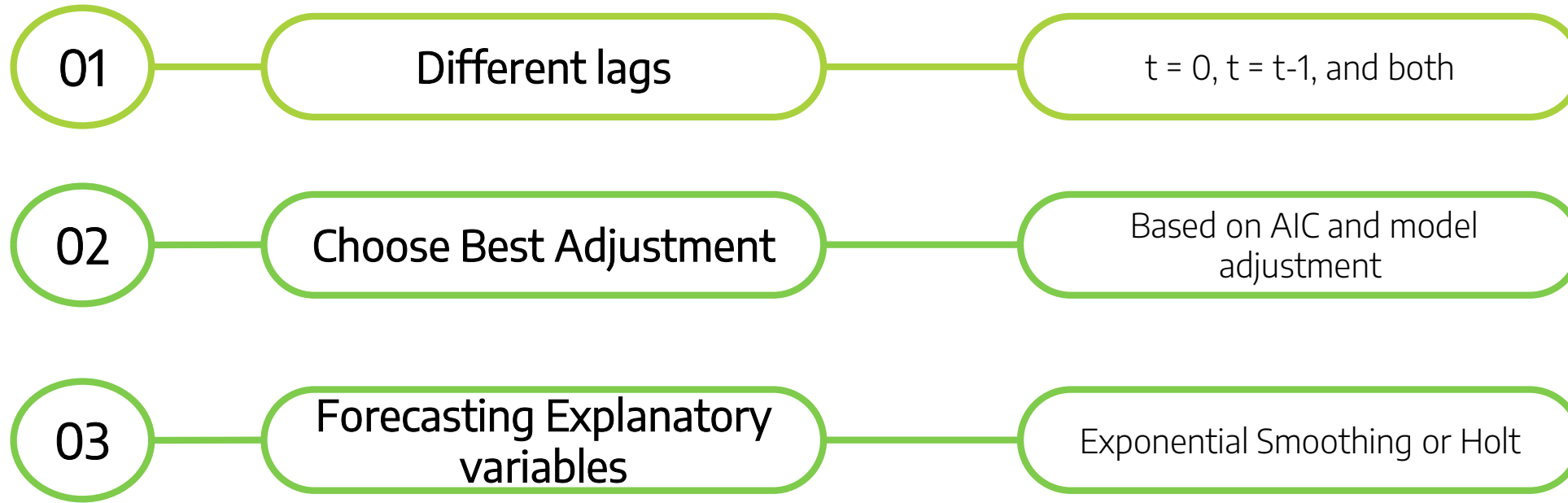
## Google Trends

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

## Stock Market

- Albemarle
- Mineral Resources
- SQM

# ARMAX Explanatory Variables

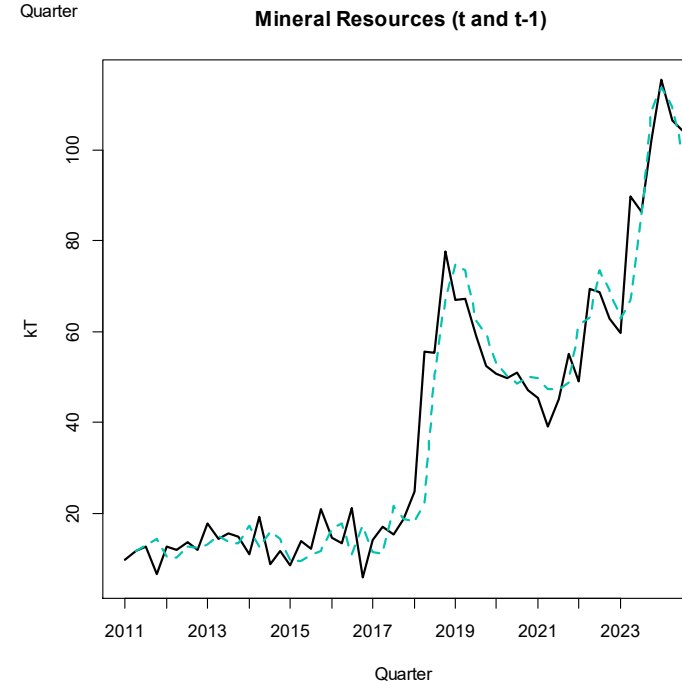
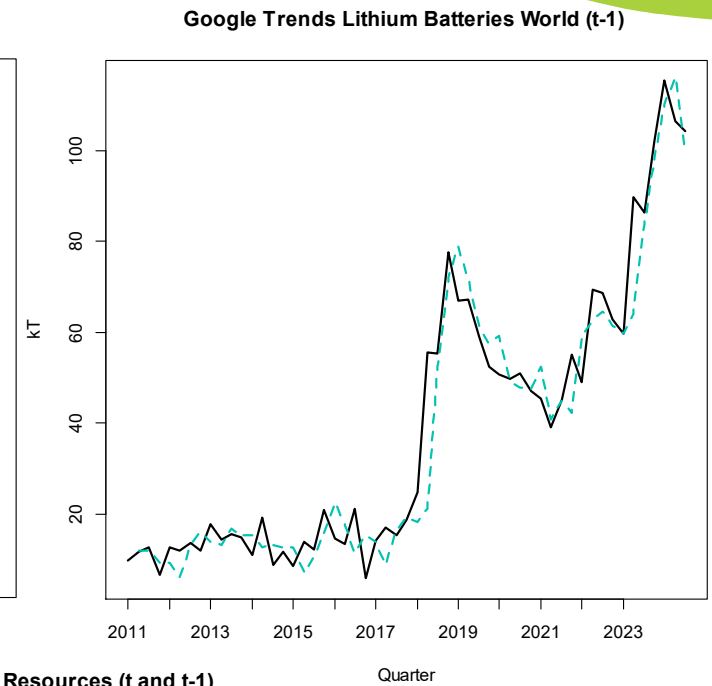
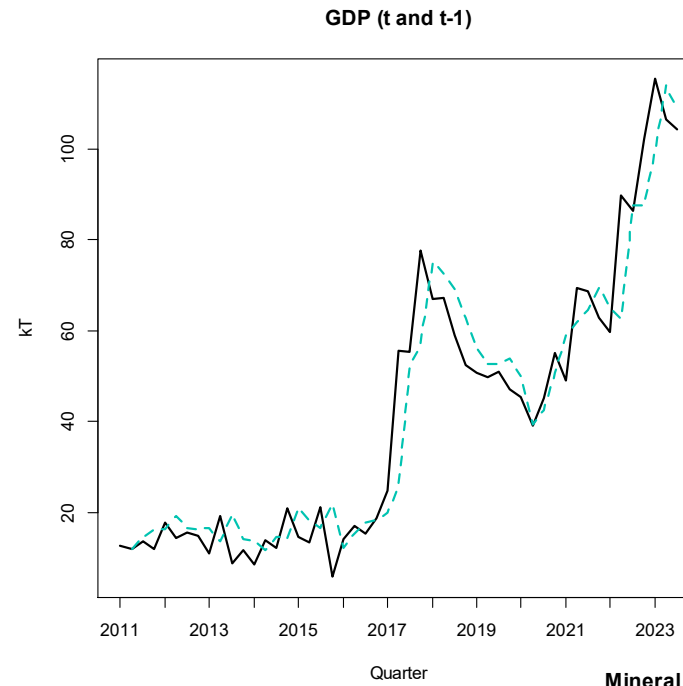


# ARMAX Australia

Comments:

- Similar adjustments. Differences in certain periods.

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

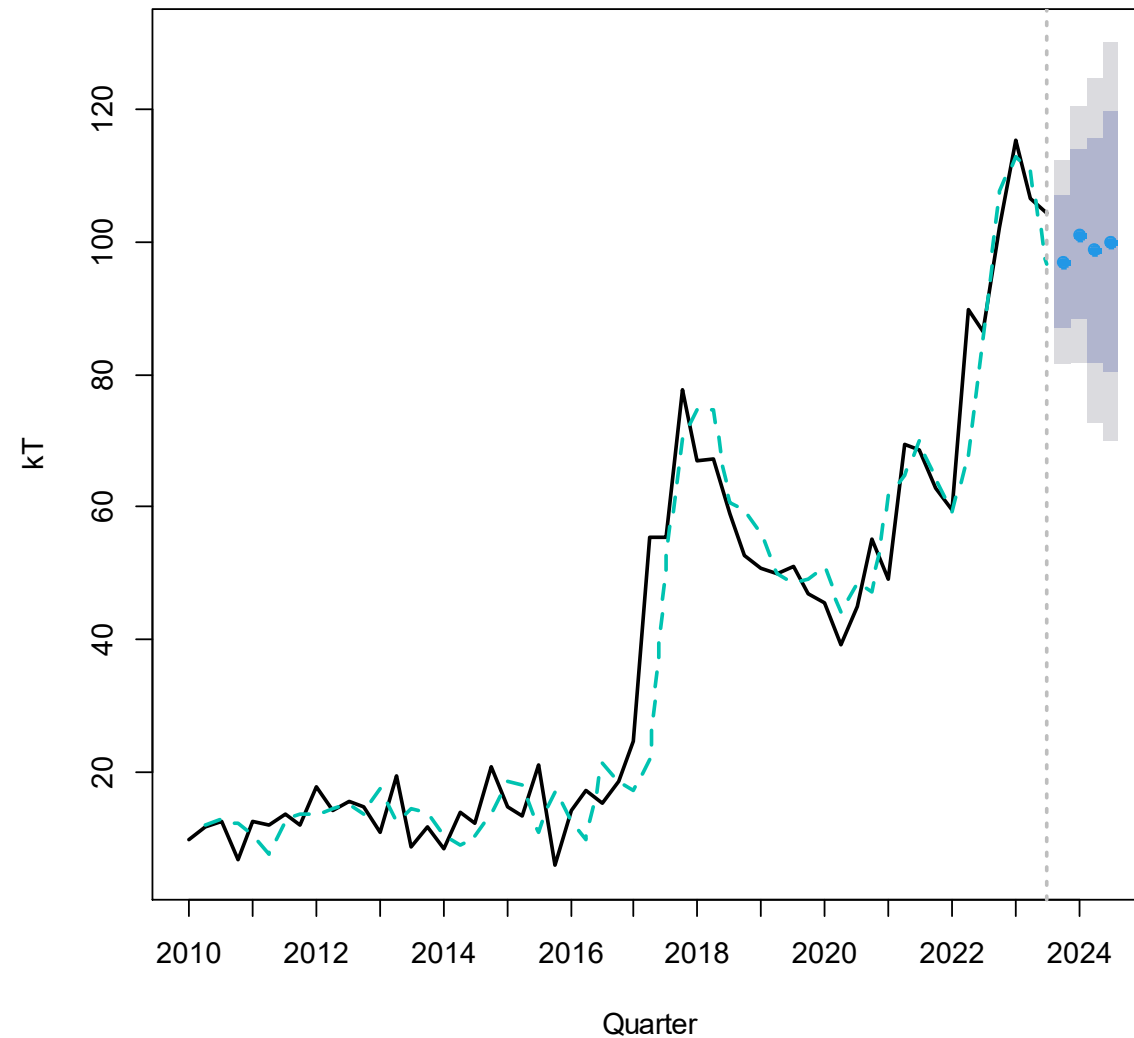


# ARMAX Australia

Comments:

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

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

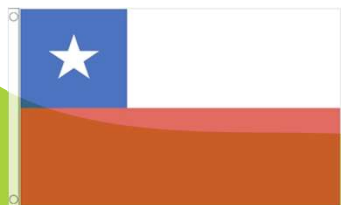


# ARMAX Chile

Comments:

- Differences in the adjustment, by period and peaks

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



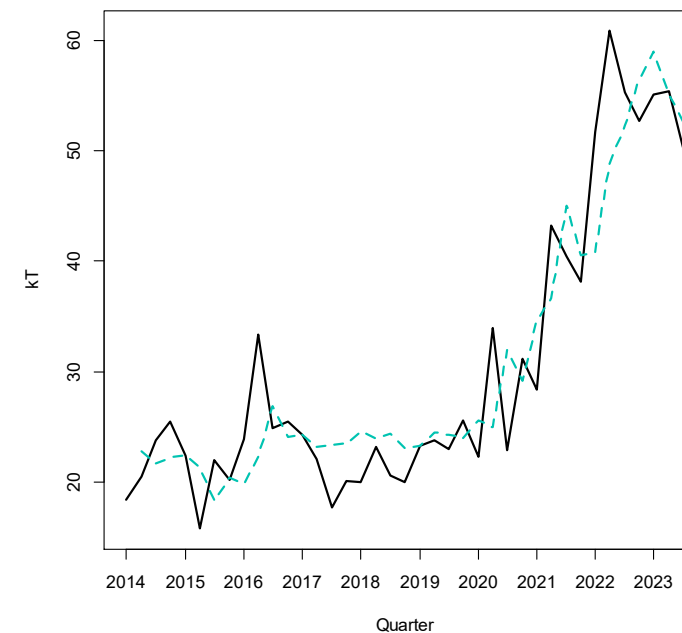
Google Trends Lithium Batteries World (t-1)



SQM (t-1)



Mineral Resoueces (t and t-1)

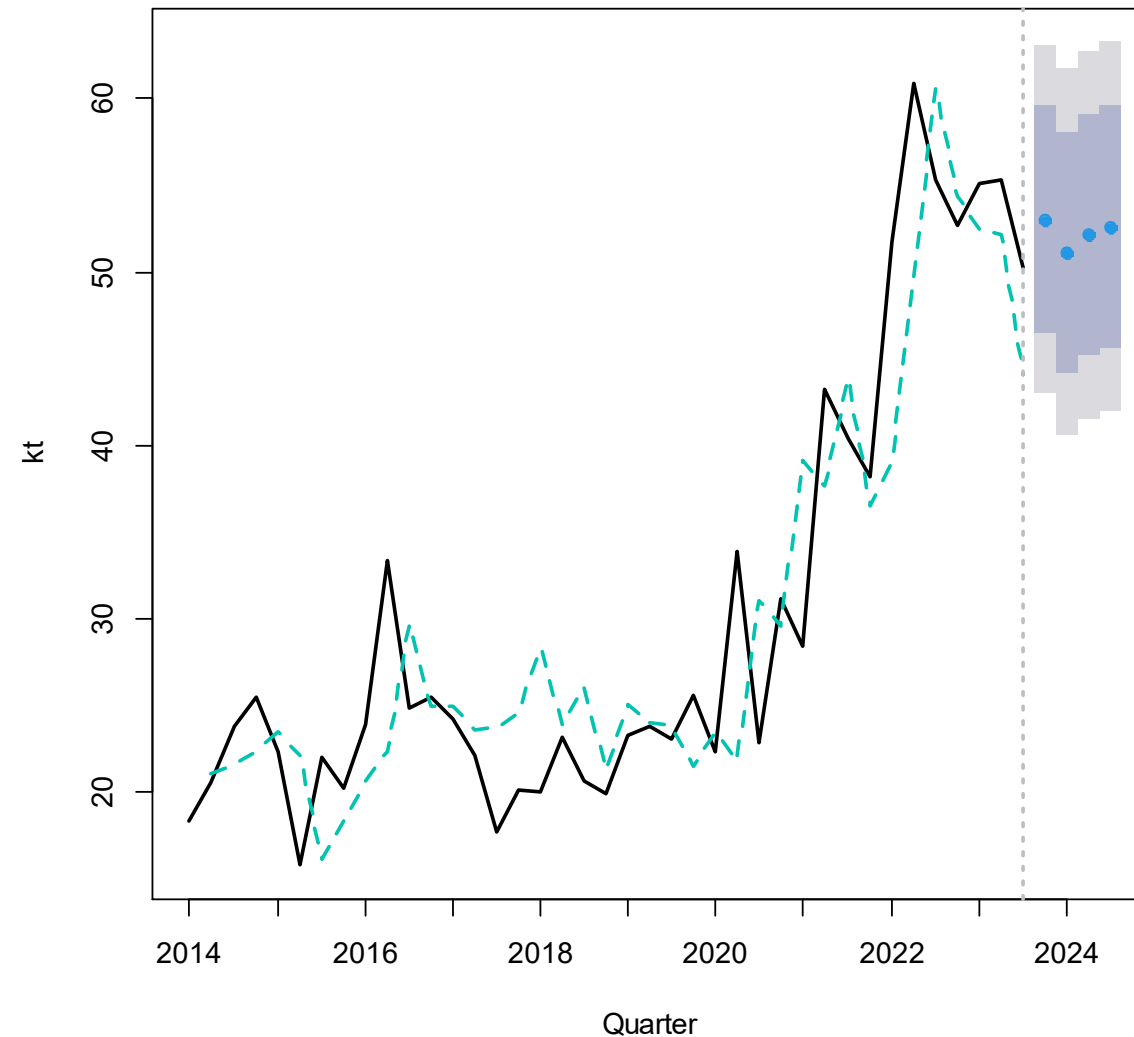
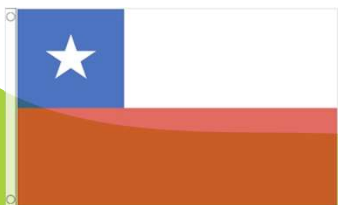


# ARMAX Chile

Comments:

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

Variable	Time	Forecasting
SQM stock	t-1	Exponential Smoothing
Lithium Bateriaes 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
<b>ARMAX(1,1,0) with errors</b>	<b>13.39</b>



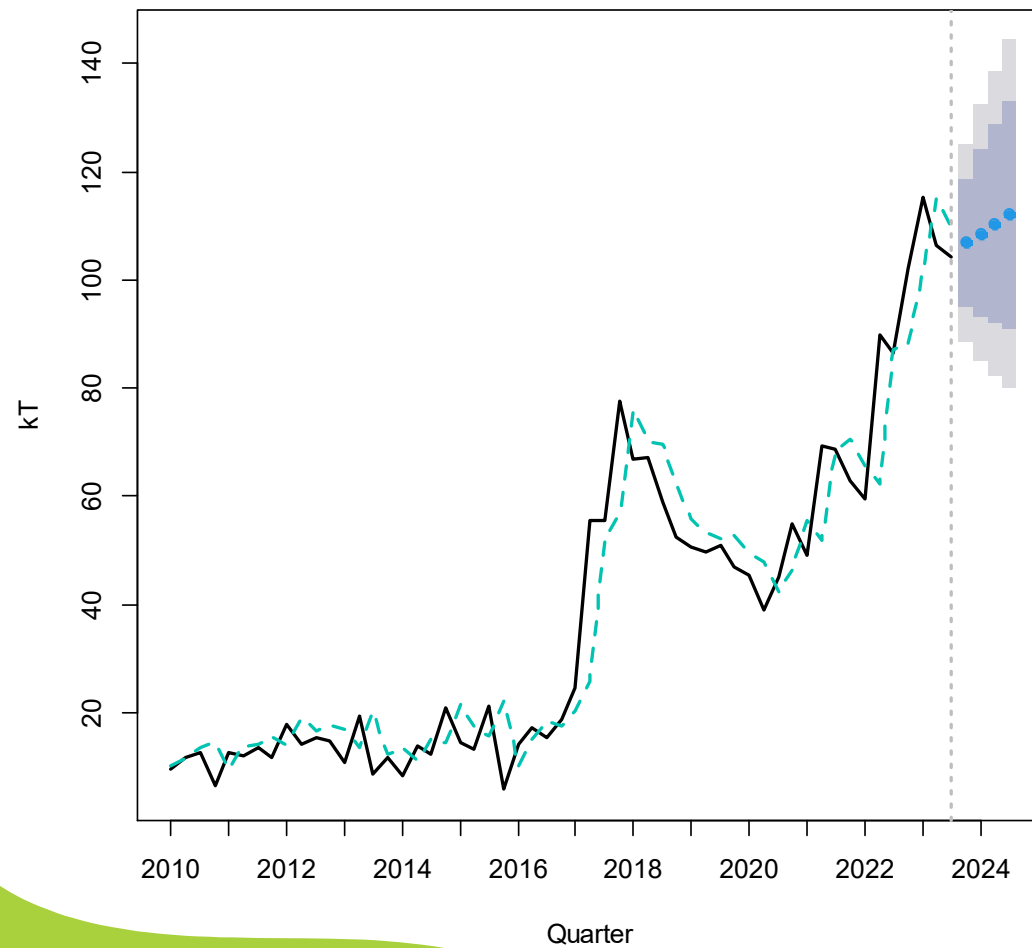
# Forecasting Australia and Chile

## Comments:

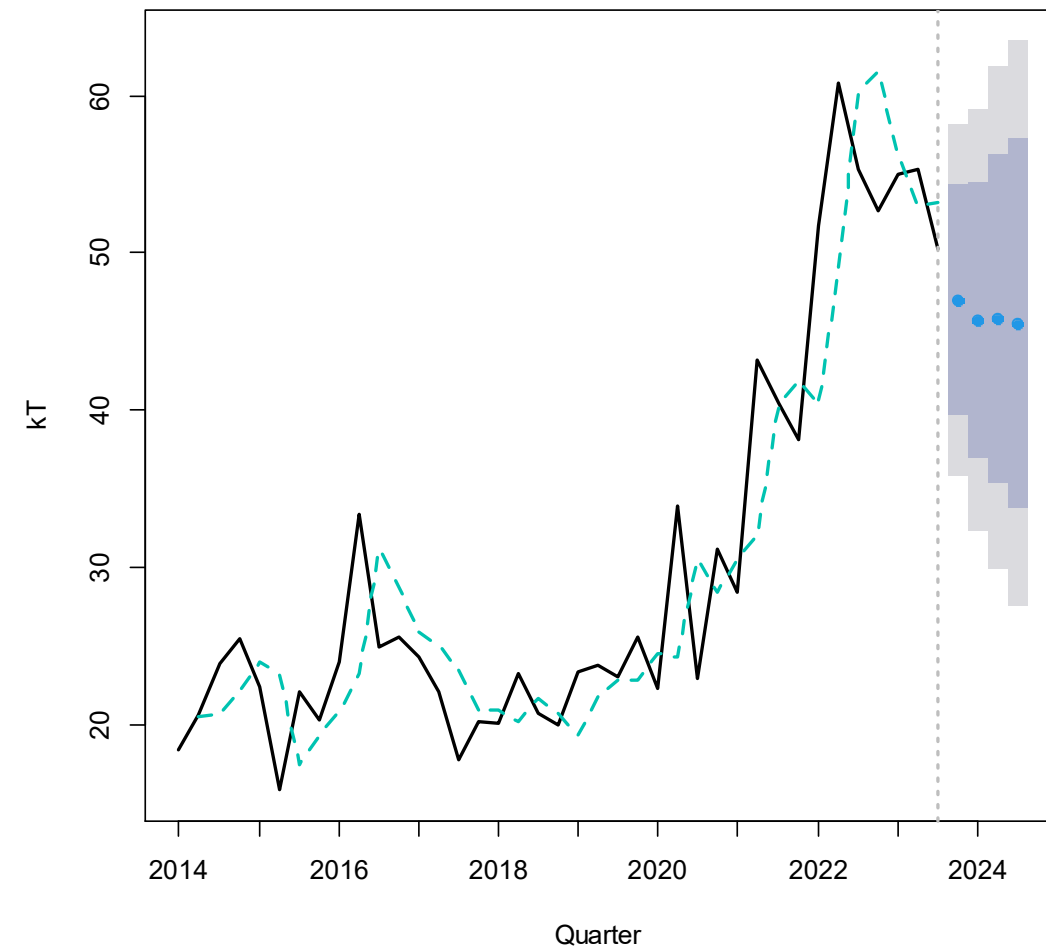
- In the case of Australia, Holt's Exponential Smoothing is the model with the best MAPE
- In the case of Chile, ARMAX with explanatory variables has a low MAPE
- Forecasting will depend on the forecasting of explanatory variables
- Exports of lithium are expected to have a moderate or increasing behaviour
- 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<sup>1,2</sup>
- Australia is facing competition from the “lithium triangle” of Chile, Bolivia, and Argentina<sup>3</sup>
- 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<sup>4</sup>

Albemarle’s  
lithium refinery  
plant, Australia



Latin America's  
Lithium Triangle

Source: <sup>1</sup>[ABC News Australia](#), <sup>2</sup>[Australian Resources and Investment Mining Journal](#), <sup>3</sup>[The Guardian](#), <sup>4</sup>[Financial Times](#)

Padova, another  
player in the clean  
technology  
expansion race



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Alejandra Cruces Andrews

