Zero Energy Day:

How Nationwide Blackouts Affect the Economy

Luis Gonzales [1] Koichiro Ito[2] Mar Reguant[3]

[1]Central Bank of Chile (lgonzalesc@bcentral.cl)

[2]University of Chicago and NBER (ito@uchicago.edu)

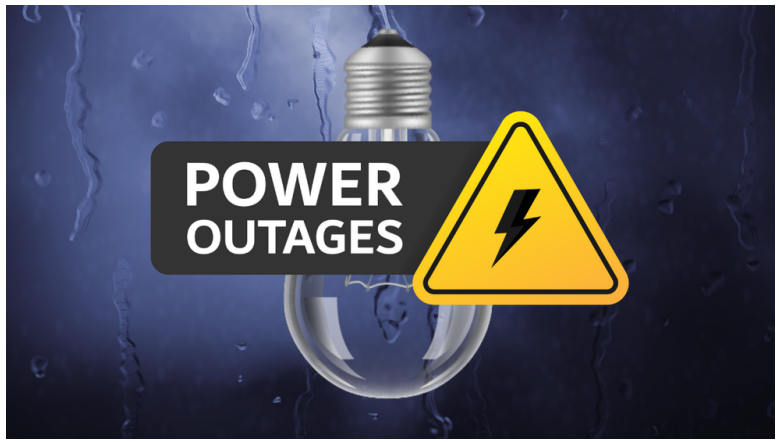
[3]Northwestern, BSE, CEPR, and NBER (mar.reguant@northwestern.edu)

Disclaimer: The views expressed are those of the author and do not necessarily reflect the views of the Central Bank of Chile or its board members. This study was developed within the scope of the research agenda conducted by the Central Bank of Chile (CBC) in economic and financial affairs of its competence. The CBC has access to anonymized information from various public and private entities, by virtue of collaboration agreements signed with these institutions.
Acknowledgment: We would like to thank Paula Araya, Linnea Holy, and Yura Mizutani for their exceptional research assistance.

Recent events drew attention to nationwide blackouts

- 2025 Chile blackout on February 25, 2025
  - Lasted up to 24 hours. Over 90% of the population was affected
- 2025 Iberian Peninsula blackout (Spain and Portugal) on April 28
  - Lasted about 10 hours.
  - 60% of Spain's demand and 98% of Portugal's demand were affected

Electricity reliability is a key issue in energy transition



1. Rising global electricity demand with limited or aging infrastructure
   - US and Europe are facing rising demand with aging infrastructure
   - Developing world is facing rising demand with limited infrastructure
2. Climate change and extreme weather
   - Natural disasters strain electrical infrastructure, causing blackouts and increasing maintenance costs (Warner, Callaway, and Fowlie, 2025)
3. Renewable energy integration
   - The variability of solar and wind challenge grid stability

Limited empirical evidence on the value of lost load (VoLL)

- The value of lost load (VoLL)
  - Willingness to pay to avoid a disruption in their electricity service
  - A key parameter for regulators to assess the damages of blackouts
  - Mostly based on engineering modeling/simulations

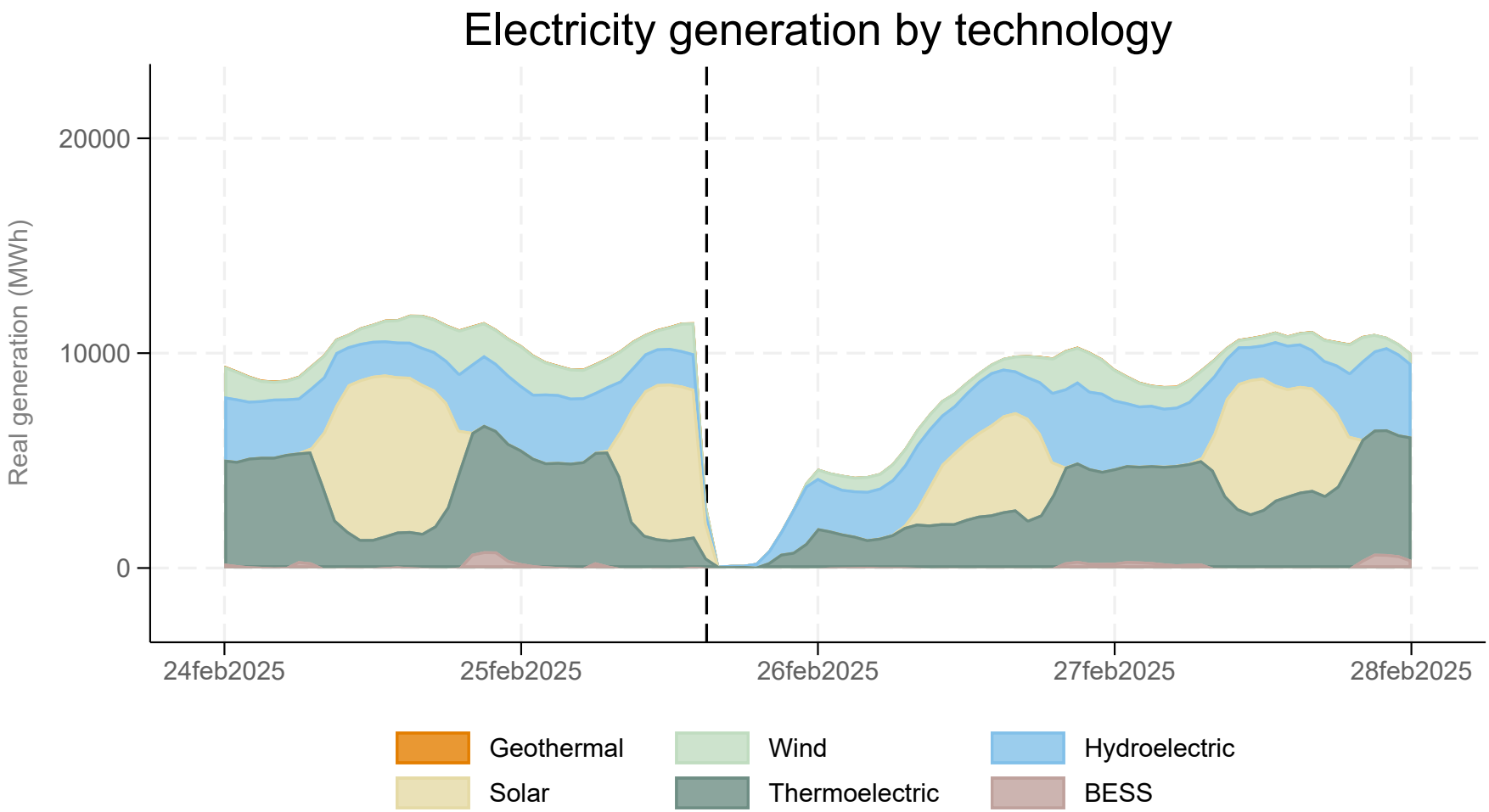
- Econ literature's focus has been electricity shortages in manufacturing
  - Impact of electricity shortages on productivity in manufacturing sectors (Fisher-Vanden, Mansur, Wang, 2015, Allcott, Collard-Wexler, O'Connel)
  - Evidence on 1) other sectors and 2) nationwide blackouts (as opposed to localized load sheddings) is limited

We study the impact of Chile's recent nationwide blackouts

- Examine the impact of Chile's nationwide blackout on its retail sector
- Combine electricity data and administrative tax records in Chile
  - Node-level hourly electricity demand data
  - Administrative tax records on daily retail sales
- Estimate the blackout-day damage and intertemporal rebound
  - Heterogeneity by sector by region
- Aim to provide valuable insights for the Value of lost load (VoLL)
  - Among the first paper to provide empirical evidence on the VoLL
  - Caveat: Our current focus is retail sectors only

Background

What happened on February 25, 2025?



Note: Dashed line represents blackout hour, i.e., 25 February 2025 at 15:00.

- The blackout started at 15:16 on February 25 (Tue) in 2025
- A partial recovery by the night, but it took $\approx$ 24h to fully recover

Why did it happen? It started in Coquimbo region

- The blackout was triggered by a malfunction in electronic and software protection systems by an energy distributor ISA Interchile
- As a result, a 500 kV double-circuit high-voltage line in this area failed and disconnected

Frist oficial technical diagnostic report

- **Event:** Total blackout of the Chilean National Electric System (SEN).
- **Date and Time:** February 25, 2025, at 15:16 hrs.
- **Disconnection:** 100% of national demand (11,066 MW).
- **Affected installation:** Both circuits of the 2x500 kV Nueva Maitencillo - Nueva Pan de Azcar line, owned by Interchile S.A.
- **Failed element:** Protection System No. 1 of each circuit, specifically the line differential function (87L) in Siemens 7SL87 relays.

Data

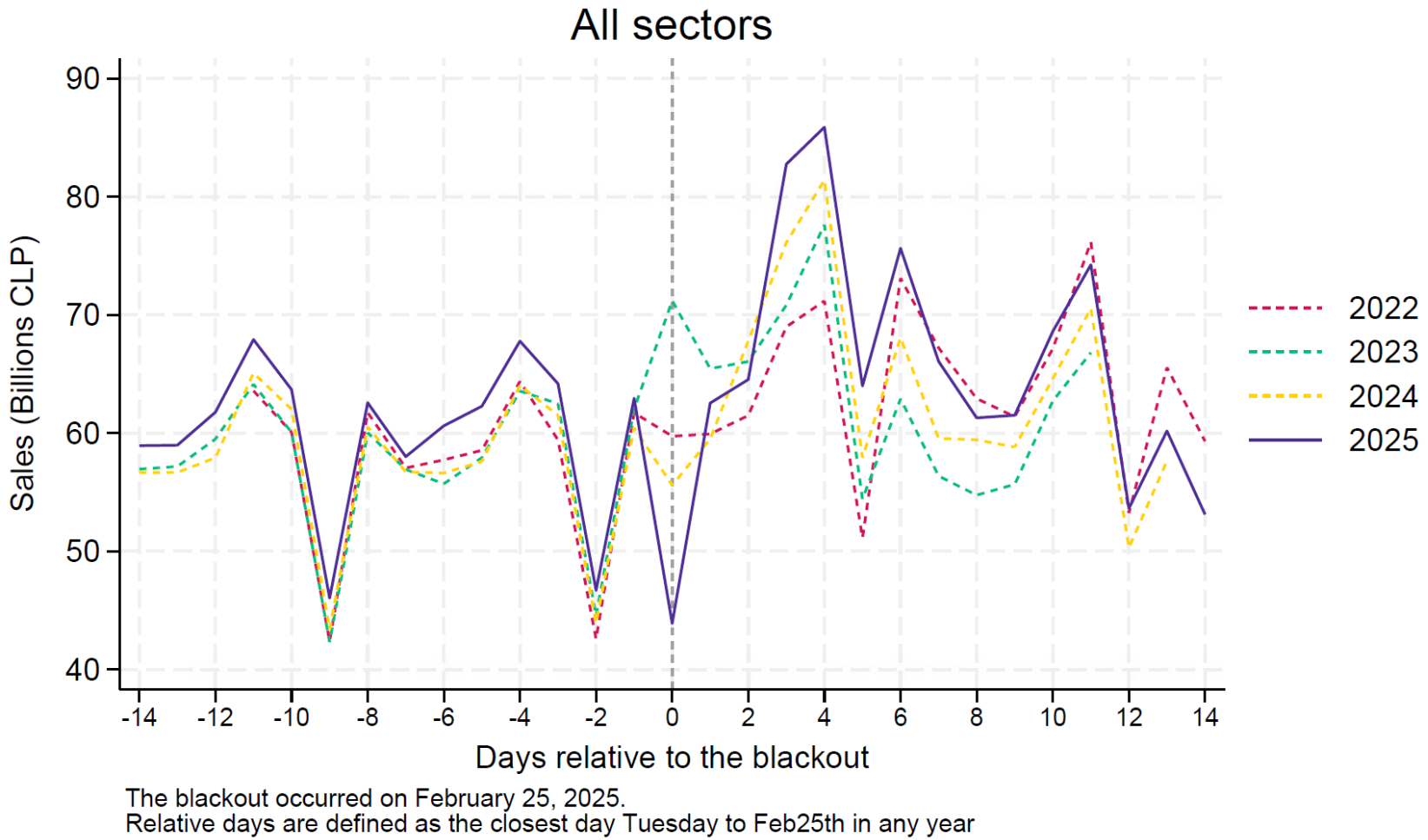
1) Electricity demand and 2) Administrative tax records

1. Hourly electricity demand at the node level (2017-2025)
   - Publicly available
   - There are over 1,000 nodes in Chile.
   - We aggregate it to commune levels

2. Administrative tax records on daily retail sales (2018-2025)
   - Confidential data from the Chilean government
   - Daily transaction data at the retail store level
   - Transacted amount and taxes
   - Advantage: Tax records provide comprehensive daily retail transactions
   - Limitation: Daily data are not available for non-retail sectors

Results 1: Aggregate impact

Raw data on aggregate daily sales (in billion Chilean pesos)



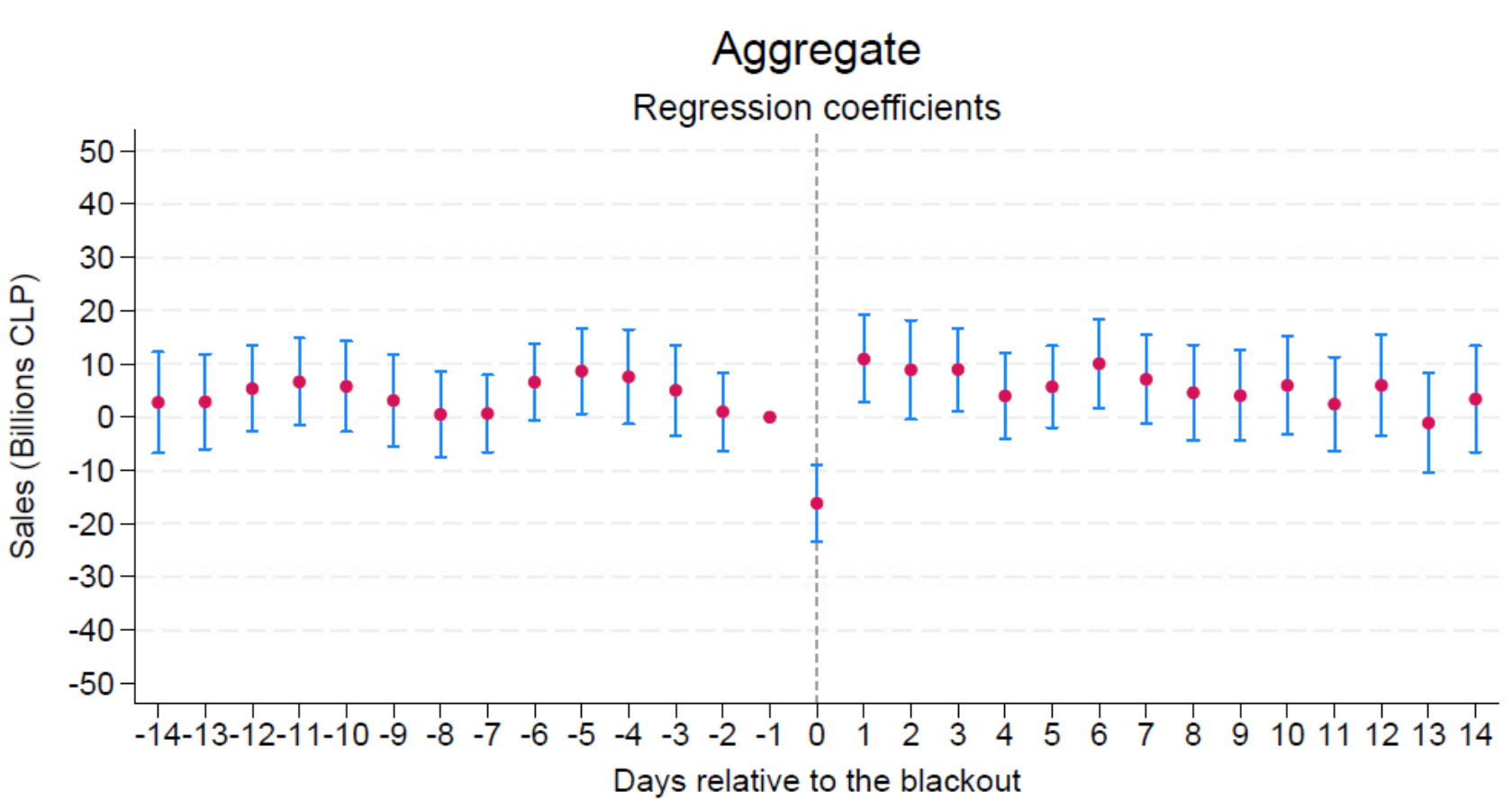
- The blackout day was February 25 (Tue) in 2025
- X-axis = days relative to the last Tuesday in February

Event study analysis

$$Y_{td} = \sum_{j=-14}^{14} \beta_j \cdot D_{j,2025} + \theta_t + \theta_j + \theta_d + \epsilon_{td} \tag{1}$$

- Y_{td} = Aggregate retail sales (in Chilean peso) in year t on day d
- j = Event-time relative to the blackout day, Feb. 25 (Tue) in 2025
- For 2022-2024, j = event-time relative to the last Tuesday in February
- $D_{j,2025} = 1$ if $t = 2025$ and $d = j$
- θ_t: Year FE
- θ_j: Event-time FE (e.g. control for February's last Tues, Wed,...)
- θ_d: Calendar day FE (e.g. control for February 25, 26,...)

Event study regression results ($\hat{\beta}_j$)



- Controls: year FE, event day FE, and calendar day FE
- Finding: Aggregate sales dropped by $\approx$ 15-20 billion peso (a 40% decline)

Outage-day effect & Intertemporal recovery effect

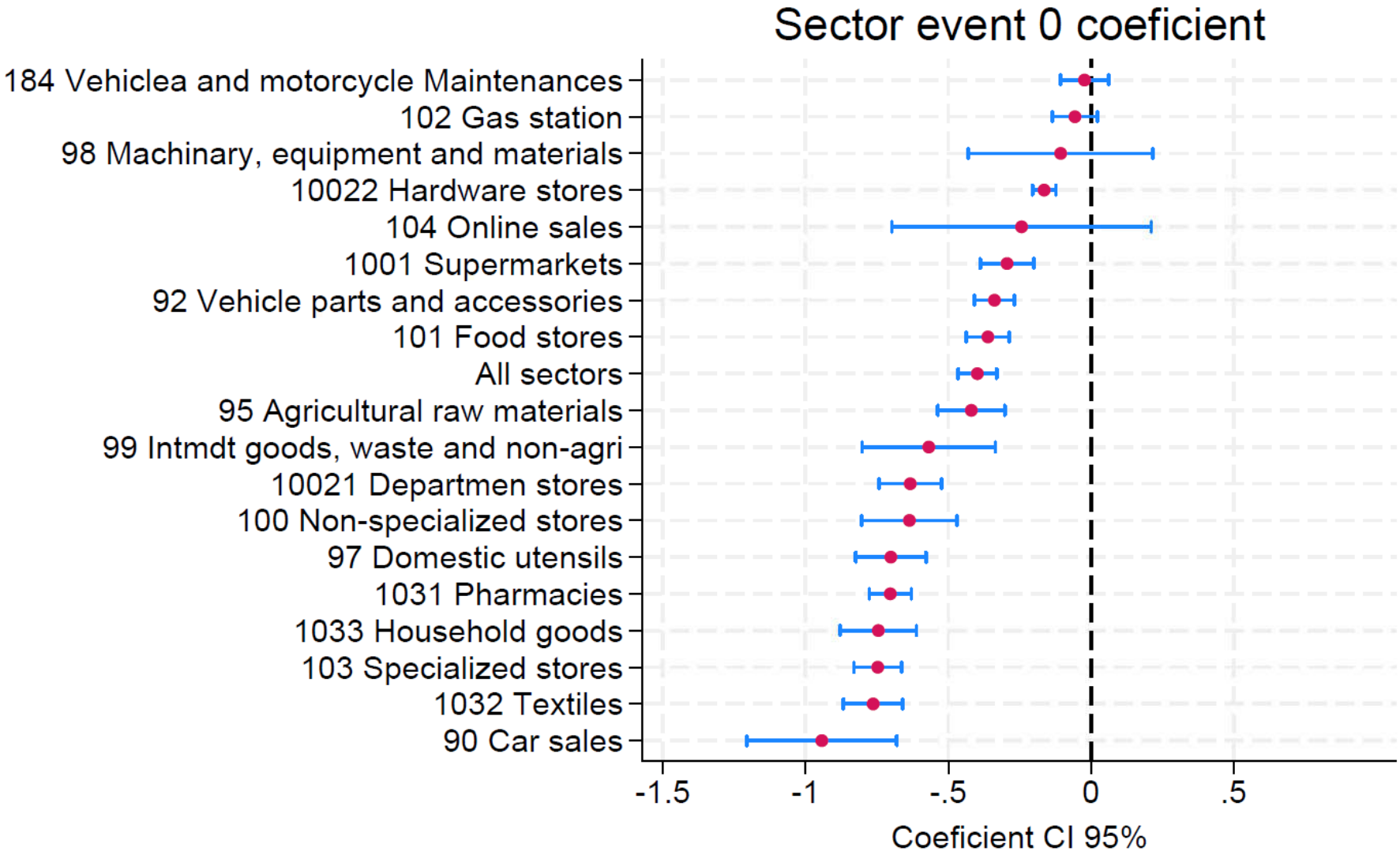
Dependent variable: Daily aggregate retail sales (Billions CLP)

	(1)
Blackout-day	-21.19
	(2.39)
1-3 days after black-out day	4.81
	(1.45)
4-14 days after black-out day	0.60
	(0.86)
Observations	116
Year FE	Yes
Event-time FE	Yes
Calendar day FE	Yes

- Outage-day effect: Aggregate sales dropped by 21 billion CLP
- Intertemporal recovery: Sales increased by 4.8 billion CLP/day in day 1-3

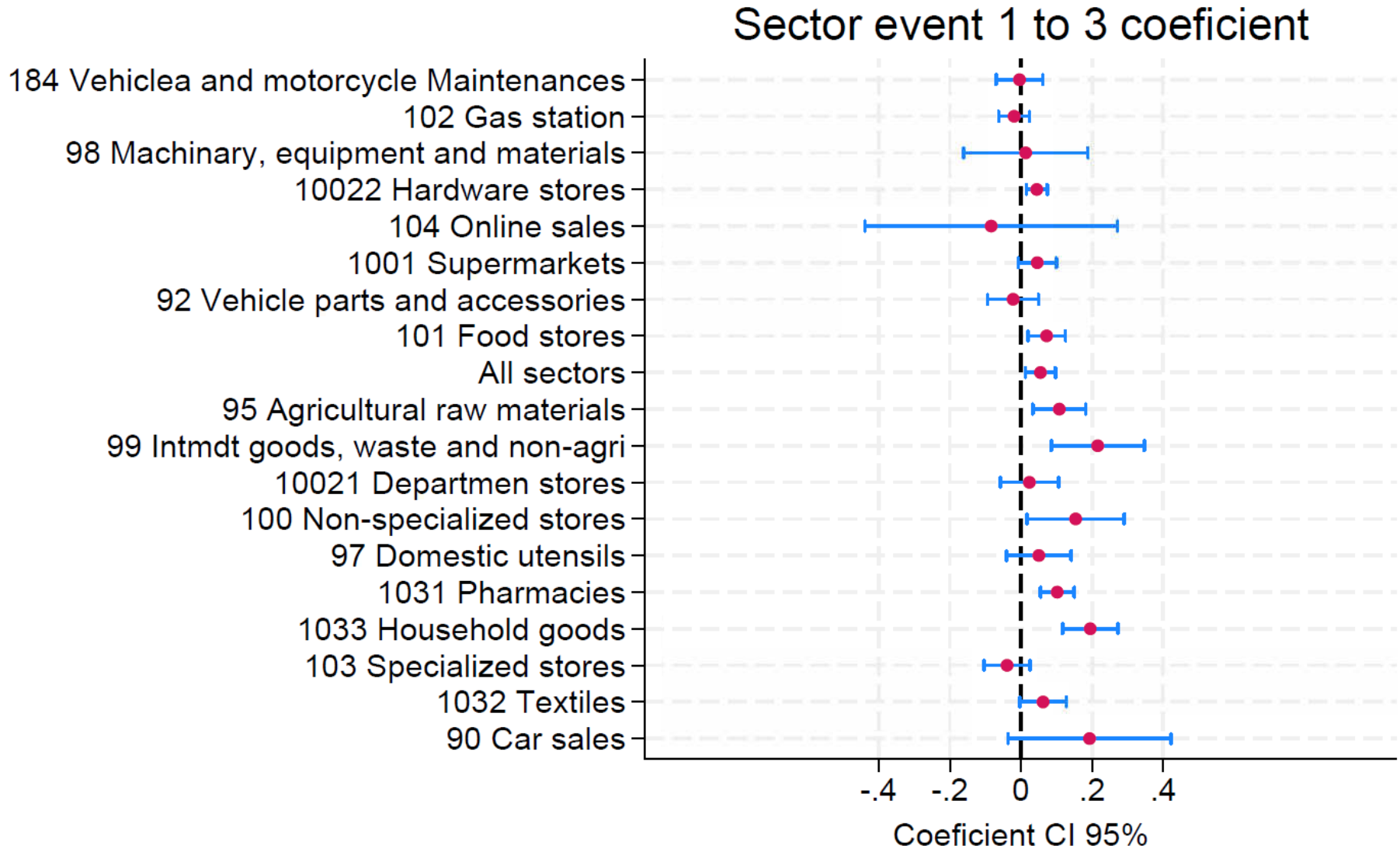
Results 2: Impact by sector

Which sectors had larger blackout-day impacts?



- The outcome variable is ln(sector-level total retail sales)
- The coefficient = the blackout-day impact on sales in log points

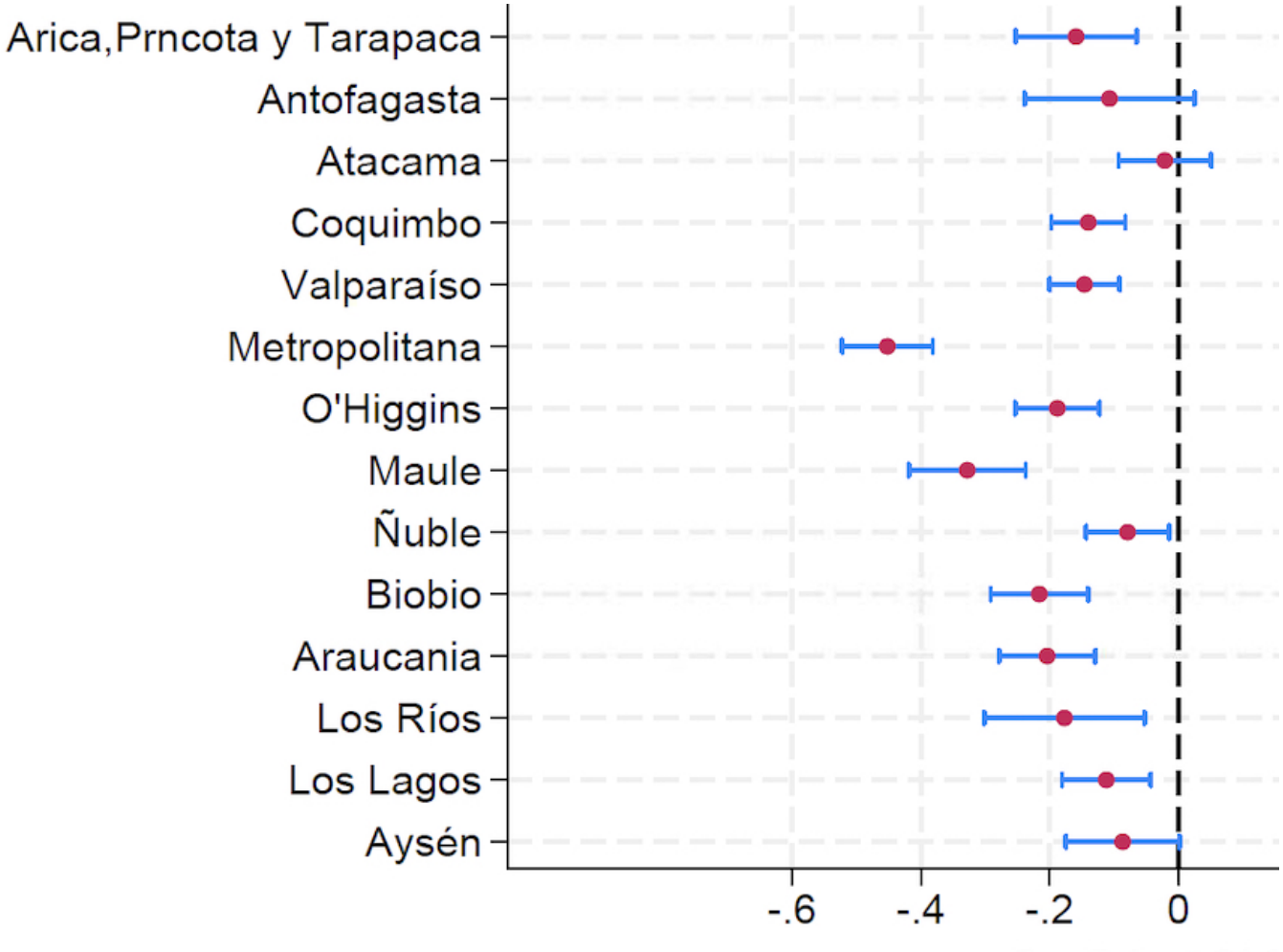
Which sectors had inter-temporal rebound effects?



- The outcome variable is ln(sector-level total retail sales)
- The coefficient = the blackout-day impact on sales in log points

Results 3: Impact by region

Which regions had larger blackout-day impacts?



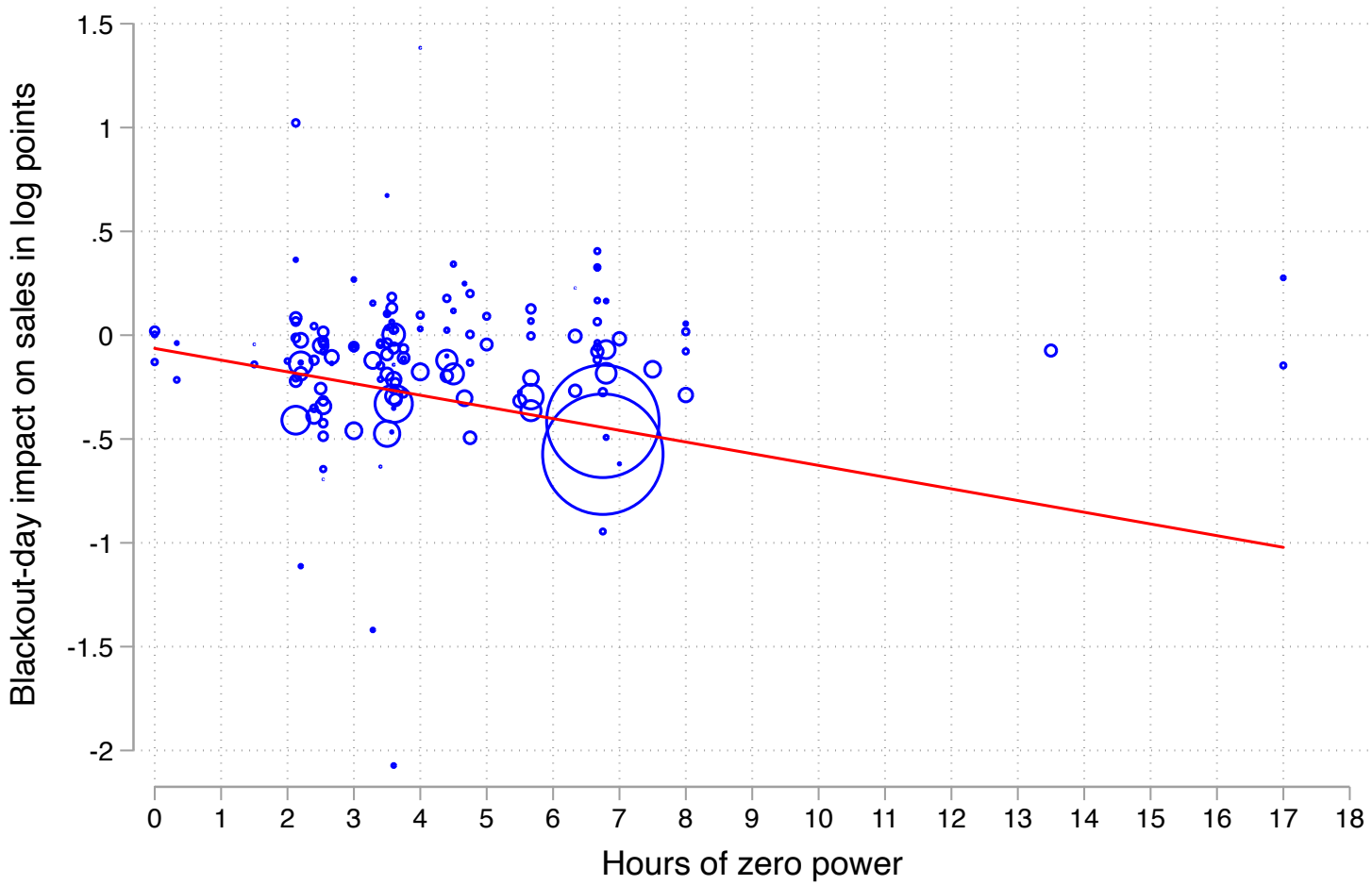
- Heterogeneous impacts across region can be due to two reasons:
  - Power recovery was faster in some regions and later in others
  - Sectoral compositions are different across regions

Results 4: Marginal effects of hourly blackouts

Can we use spatial variation to estimate a marginal effect?

- So far, we focused on the blackout event day impact
- Can we estimate $\frac{\partial \ln(Y)}{\partial h}$? ($h$ is hours of zero power)
- Node-level demand data allow us to create commune-level "zero power hours"
- Idea 1: Consider this variation as quasi-random (OLS)
- Idea 2: Construct an IV = the distance between each commune and Coquimbo (the origin of the grid failure), instrumenting for zero power hours

Blackout-day impact (Y) and hours of zero power (X)



- Y = Blackout-day impact on sales (in log points) at the commune level
- X = Hours of zero power in that commune

Marginal effects of hourly blackouts

Dependent variable: Outage-day impact on sales in log points

	(1) OLS	(2) 1st stage	(3) IV
Hours of zero power	-0.056		
	(0.015)		
Distance from Coquimbo (1,000km)			
Constant	-0.064		
	(0.060)		
Observations	140		
R^2	0.24		

- Interpretation: An additional hour of zero power is associated with a ≈ -0.056 (OLS) or ≈ -0.079 (IV) percentage point decline in retail sales
- 1st stage: cities farther from Coquimbo had fewer zero power hours

Marginal effects of hourly blackouts

Dependent variable: Outage-day impact on sales in log points

	(1) OLS	(2) 1st stage	(3) IV
Hours of zero power	-0.056		
	(0.015)		
Distance from Coquimbo (1,000km)		-3.94	
		(0.828)	
Constant	-0.064	7.76	
	(0.060)	(0.650)	
Observations	140	140	
R^2	0.24	0.35	

- Interpretation: An additional hour of zero power is associated with a ≈ -0.056 (OLS) or ≈ -0.079 (IV) percentage point decline in retail sales
- 1st stage: cities farther from Coquimbo had fewer zero power hours

Marginal effects of hourly blackouts

Dependent variable: Outage-day impact on sales in log points

	(1) OLS	(2) 1st stage	(3) IV
Hours of zero power	-0.056		-0.079
	(0.015)		(0.019)
Distance from Coquimbo (1,000km)		-3.94	
		(0.828)	
Constant	-0.064	7.76	0.068
	(0.060)	(0.650)	(0.101)
Observations	140	140	140
R^2	0.24	0.35	0.20

- Interpretation: An additional hour of zero power is associated with a ≈ -0.056 (OLS) or ≈ -0.079 (IV) percentage point decline in retail sales
- 1st stage: cities farther from Coquimbo had fewer zero power hours

Thank you! Very preliminary and feedback welcome!

Appendix

The "zero energy day" in Chile, Feb 25, 2025

1. The event
   - At 3:16 p.m., the power was disconnected from the 500 kV "Nueva Maitencillo-Nueva Pan de Azcar" transmission line, located between Vallenar and Coquimbo.
   - Line load at the time of failure: 1.800 MW total.
   - A chain reaction impacted the National Electric System (SEN), causing a blackout from Arica to Los Lagos.
2. Impact
   - Retail sales, transportation, telecommunications, mining, mass events, etc.
3. Policies reaction
   - Declaration of a state of emergency "Toque de queda".
   - Progressive restoration of electricity supply

SEN a interconected electric system

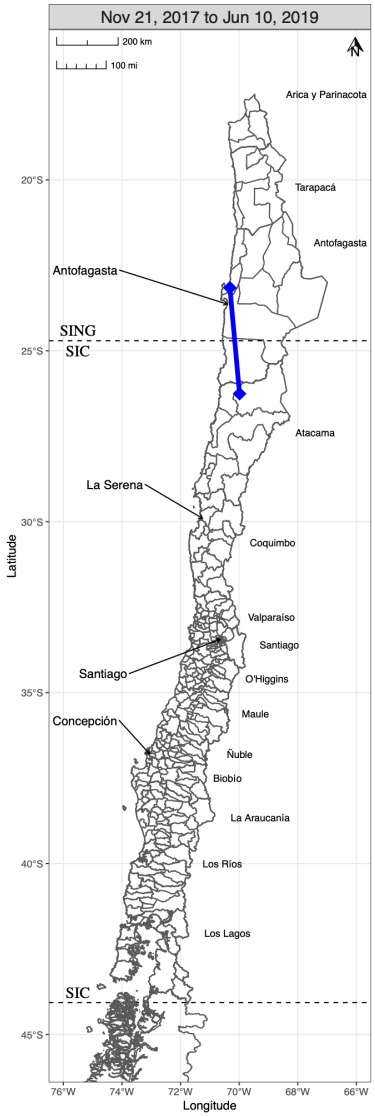


Figure: SING-SIC interconnection.

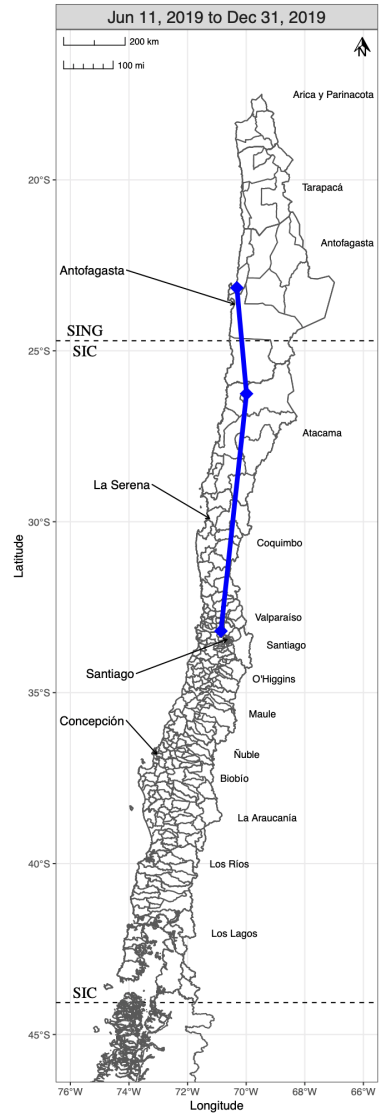


Figure: SEN system

Commune Coquimbo: The origin of the collapse

Figure: SEN electric system map.

Figure: 500kV circuits that fail and disconnect

- Max Capacity 1.600MW (Sup/def 1.800MW)
- Location: Vallenar - Coquimbo
- Longitud: 212 Km

The "zero energy day" in Chile, Feb 25, 2025

- **13:35 hrs**: Interchile reports the failure of the main communications module of function transmision line Maintencillo - Pan azucar, the backup communications system is operational.
- **15:16 hrs**: CDC stops receiving signals from companies in most SEN facilities. The Coordinator's emergency system remains operational, but with outdated and poor quality information.
- **15:17 hrs**: Interchile's CC reports an event at Nueva Pan de Azcar Substation, with an investigation into the cause.
- **15:19 hrs**: CDC instructs Enel Generacion's CC to conduct a survey of the conditions of its facilities and prepare to implement the Service Recovery Plan (SRP).
- **15:36 hrs**: Transelec CC notifies that its SCADA and telephone systems are out of service.
- **16:24 hrs**: 24% of Arica's consumption is recovered
- **17:00 hrs**: 25% of Puerto Montt recovered
- **20:17 hrs**: Barrio Civico is being recovered and consumption recovery will begin.

Source: **Coordinador El©ctrico - Daily report Feb 25, 2025**

Frist oficial technical diagnostic report

- **Event:** Total blackout of the Chilean National Electric System (SEN).
- **Date and Time:** February 25, 2025, at 15:16 hrs.
- **Disconnection:** 100% of national demand (11,066 MW).
- **Affected installation:** Both circuits of the 2x500 kV Nueva Maitencillo - Nueva Pan de Azcar line, owned by Interchile S.A.
- **Failed element:** Protection System No. 1 of each circuit, specifically the line differential function (87L) in Siemens 7SL87 relays.

Origin and Cause of the Failure

- **Sequence:** Unexpected breaker openings at both substations without actual faults.
- **Reconnection:** Attempted but insufficient to restore the system.
- **Consequences:** Power oscillations, islanding, and collapse of both islands.
- **Technical cause:** Unexpected operation of 87L due to failed communication module and resynchronization attempt.
- **Investigation:** Ongoing; final report expected Q2 2025.

  At 15:15:41.363, while attempting to restore the communication channel and resynchronize the line differential protection function, an unexpected and unintentional activation of the protection system occurred.

For more details, refer to the official report:
Coordinador Electrico de Chile Feb 18, 2025