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)

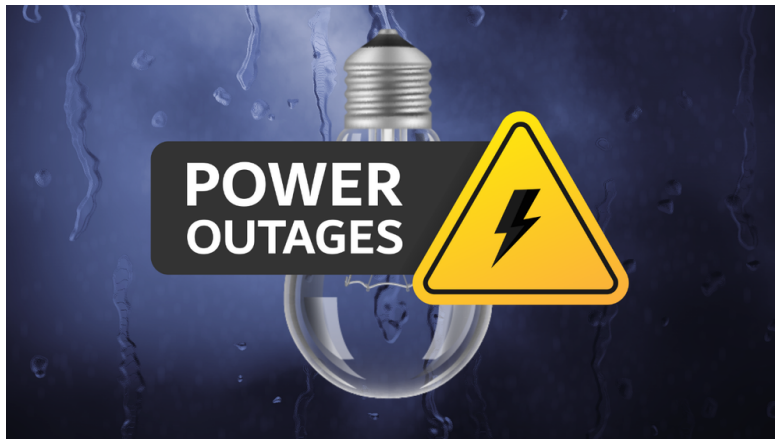
[3]Northwestern, BSE, CEPR, and NBER (mar.reguant@northwestern.edu)

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 for 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)
  - How much economic values would be lost due to lost load
  - It is a key parameter to assess blackout damages and mitigation benefits
  - To date, most estimates are based on engineering modeling/simulations

We study how nationwide blackouts affect the economy

1. Integrate data from 1) Electricity market and 2) Central Bank of Chile
   - Hourly electricity demand data at the node-level
   - Hourly electricity supply data at the power plant unit level
   - Administrative tax records on daily retail sales
   - Transbank data: retail & wholesale transactions by credit, debit, POS

2. Estimate 1) blackout-day impact and 2) inter-temporal recovery effect
   - Blackout-day impact: -35% on economic activity
   - Inter-temporal recovery effect: $+15\%$ on economic activity
   - Heterogeneity by sector both in the impact and intertemporal recovery
   - Important b/c most studies and policy discussions ignore recovery effects

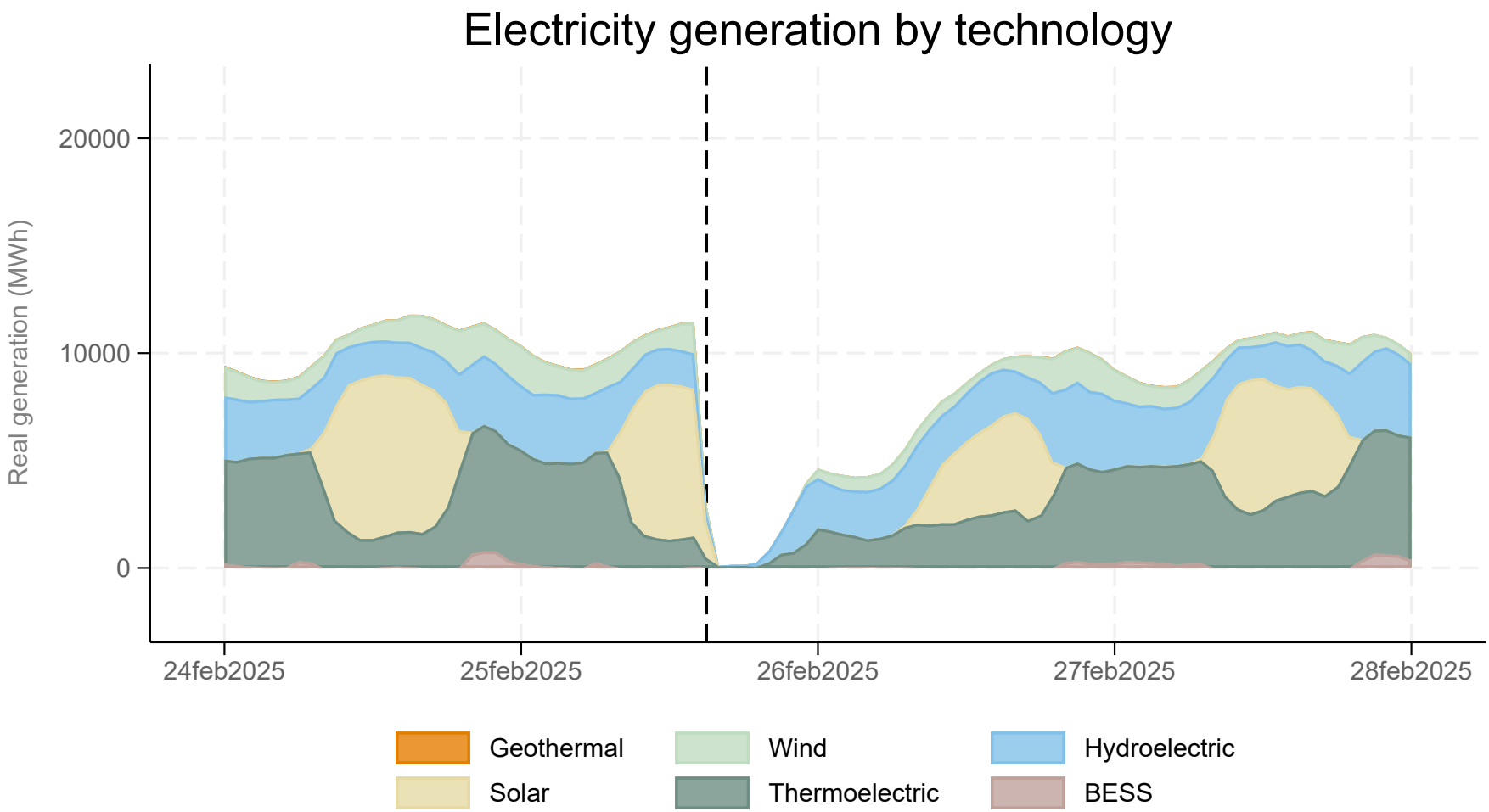
3. Aim to provide valuable insights for the Value of lost load (VoLL)

Road map of the talk

1. Introduction
2. Background and Data
3. Result 1: Aggregate impact
4. Result 2: Impact by economic sector
5. Result 3: Marginal effect of lost load

Background and Data

What happened on February 25, 2025?



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

- The blackout started at 3:16 pm on February 25 (Tue) in 2025
- A partial recovery by the midnight, but it took many hours to fully recover

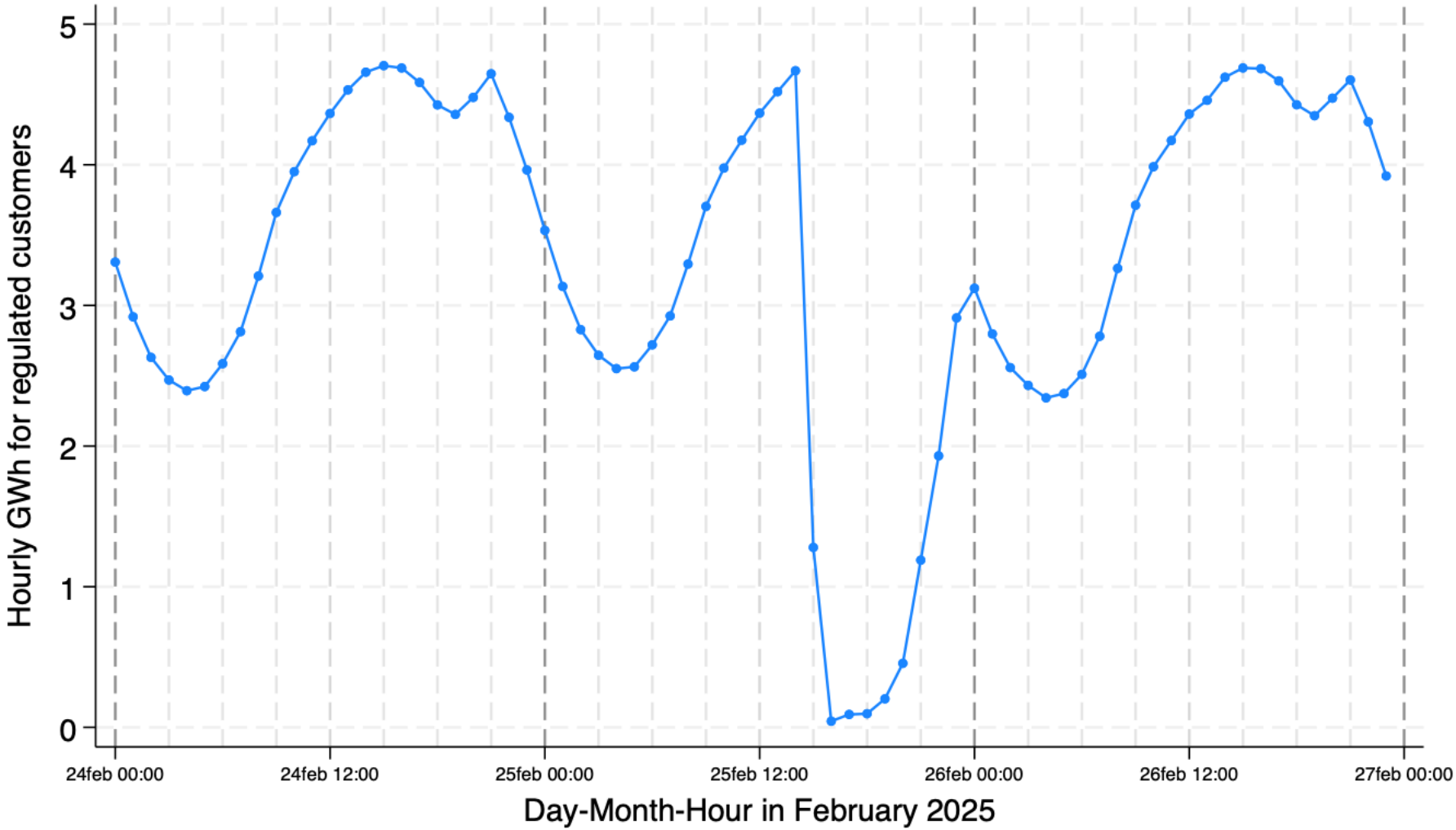
Why did it happen? It started in Coquimbo region

- 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

First official technical diagnostic report

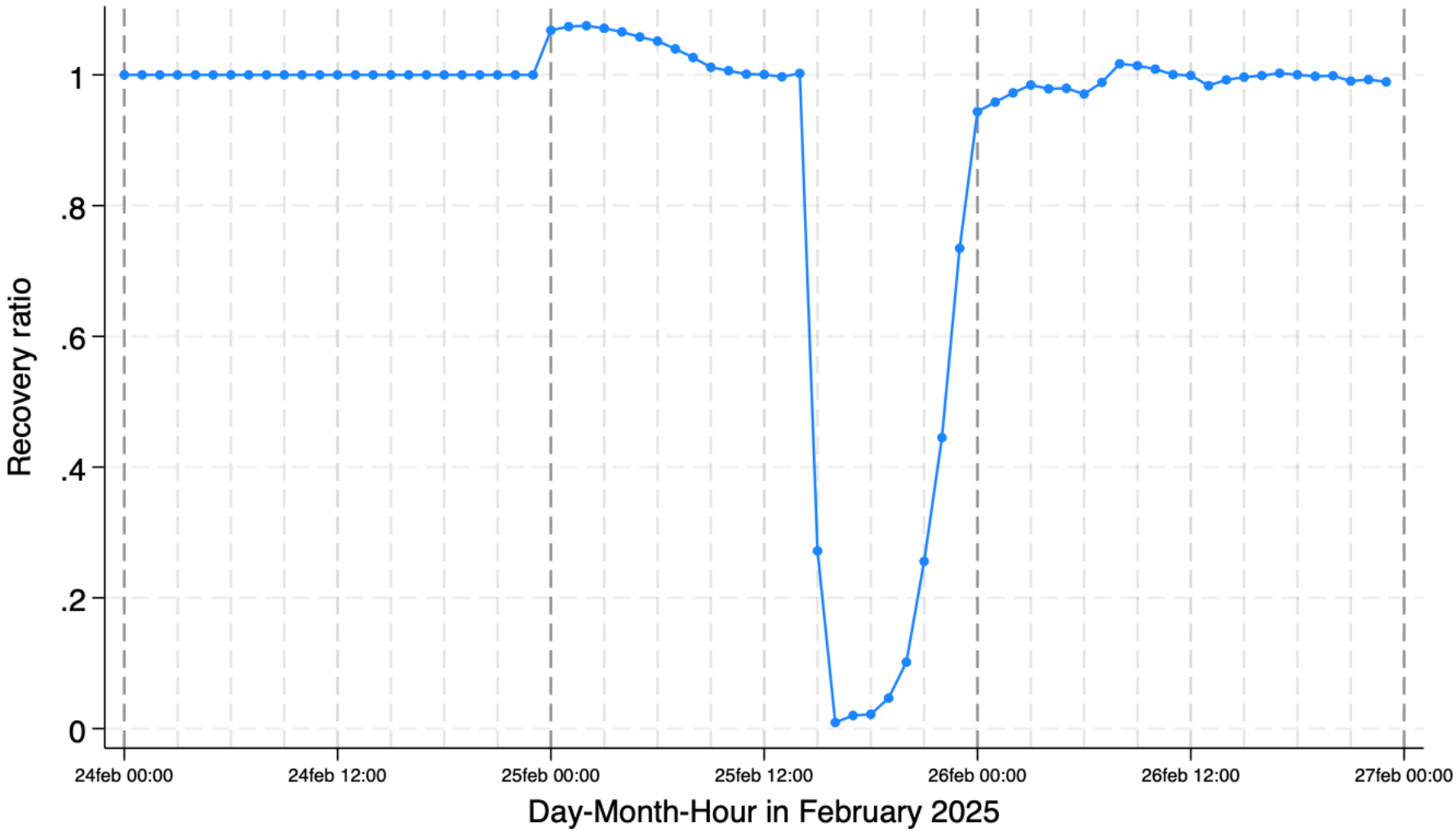
- **Event:** Total blackout of the Chilean National Electric System (SEN).
- **Date and Time:** February 25, 2025, at 15:16 hrs.
- **Disconnection:** 100% of national demand (11,066 MW).
- **Affected installation:** Both circuits of the 2x500 kV Nueva Maitencillo - Nueva Pan de Azcar line, owned by Interchile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

What happened electricity load (i.e. consumption)?



- Total electricity use for regulated customers (i.e. the majority of customers, excluding large industrial users)

Lost load (% relative to the day before)



- Most customers remained without electricity until midnight

Road map of the talk

1. Introduction
2. Background and Data
3. Result 1: Aggregate impact
4. Result 2: Impact by economic sector
5. Result 3: Marginal effect of lost load

Data

1) Electricity market data

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

2. Hourly electricity supply data at the power plant unit level (2017-2025)
   - Publicly available

2) Confidential data from Central Bank of Chile

1. Administrative tax records on daily retail sales (2018-2025)
   - Daily transaction data at the retail store level
   - Transacted amount and taxes
   - Advantage: Tax records provide comprehensive data including cash
   - Limitation: Retail transactions only

2. Transbank data—Retail & wholesale transactions by credit, debit, POS
   - Daily transaction data for any credit, debit, POS transactions
   - Transacted amount and locations
   - Advantage: Daily retail transactions at retail and wholesale
   - Limitation: No cash and check transactions, but this is small in Chile

Road map of the talk

1. Introduction
2. Background and Data
3. Result 1: Aggregate impact
4. Result 2: Impact by economic sector
5. Result 3: Marginal effect of lost load

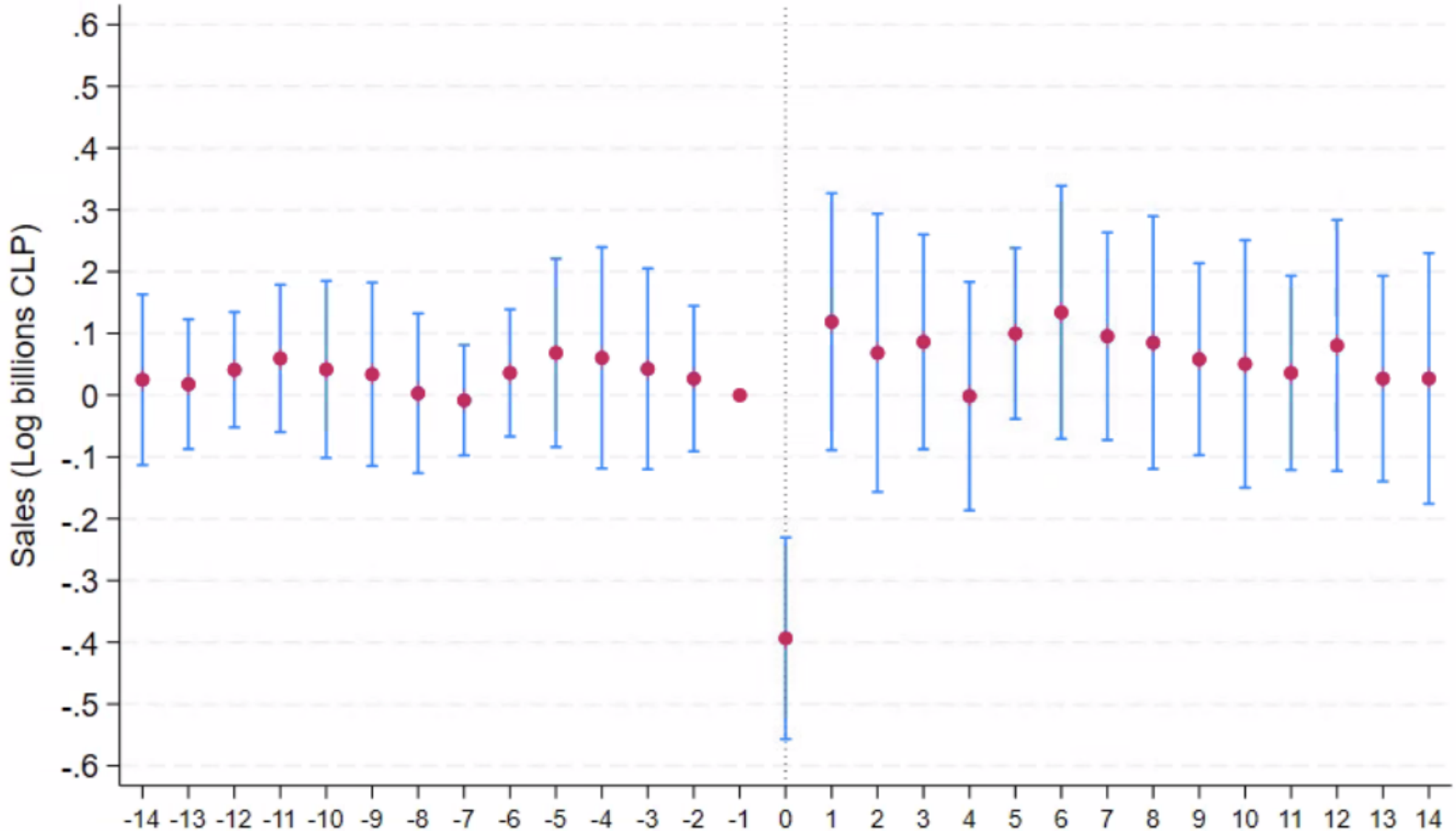
Results 1: Aggregate impact

Event study analysis

$$x_{dy} = \alpha_y + \gamma_d + \theta_j + \sum_{j=-s}^{s} \phi_j D_{j,dy} + \epsilon_{yd}, \tag{1}$$

- We use data from 2022-24
- x_{dy}: Log of aggregate retail sales (in Chilean peso) in day d and year y
- α_y: Year fixed effects
- γ_d: Calendar day FE (e.g. control for February 25, 26,...)
- $j =$ Event-time relative to the blackout day, Feb. 25 (Tue) in 2025
- For 2022-24, $j =$ event-time relative to the last Tuesday in February
- θ_j: Event-time FE (e.g. control for February's last Tues, Wed,...)
- $D_{j,dy}$ equals one if the day d in year y corresponds to event-time j and zero otherwise

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



- Controls: year FE, event day FE, and calendar day FE
- Finding: Aggregate sales dropped by 34.9%

Blackout-day impact & inter-temporal recovery effect

	Percentage Effects on Economic Activity			
All sectors	Blackout-Day Impact	Intertemporal Recovery	Net Impact	Ave. Transactions (billion CLP/day)
Tax data	-32.6 (2.7)	17.2 (9.3)	-15.4 (9.1)	3259
Transbank data	-34.9 (3.1)	15.2 (12.7)	-19.6 (11.9)	34734

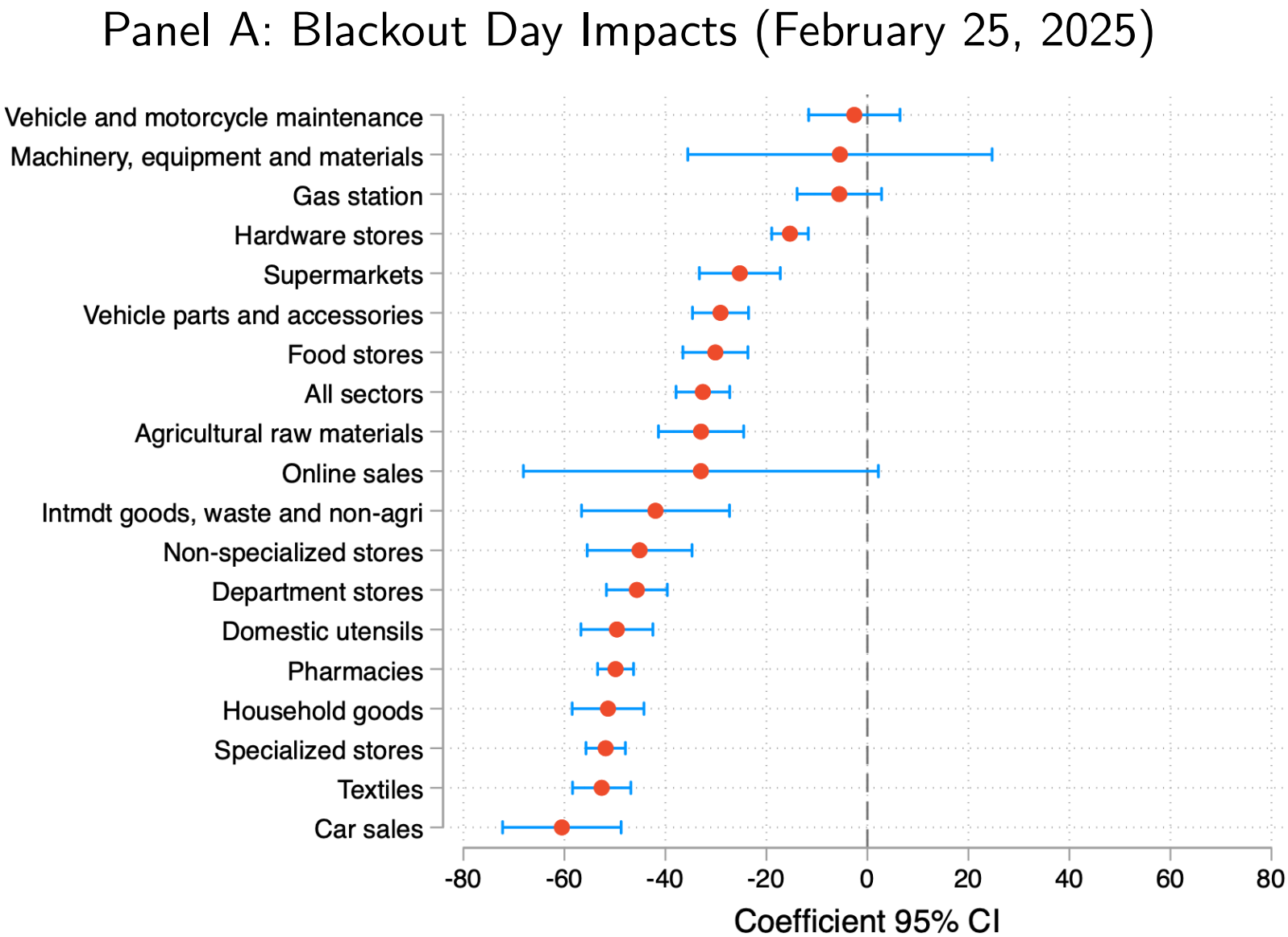
- We find quite similar results based on the two datasets
- We estimate the intertemporal recovery effects based on post 4 days

Road map of the talk

1. Introduction
2. Background and Data
3. Result 1: Aggregate impact
4. Result 2: Impact by economic sector
5. Result 3: Marginal effect of lost load

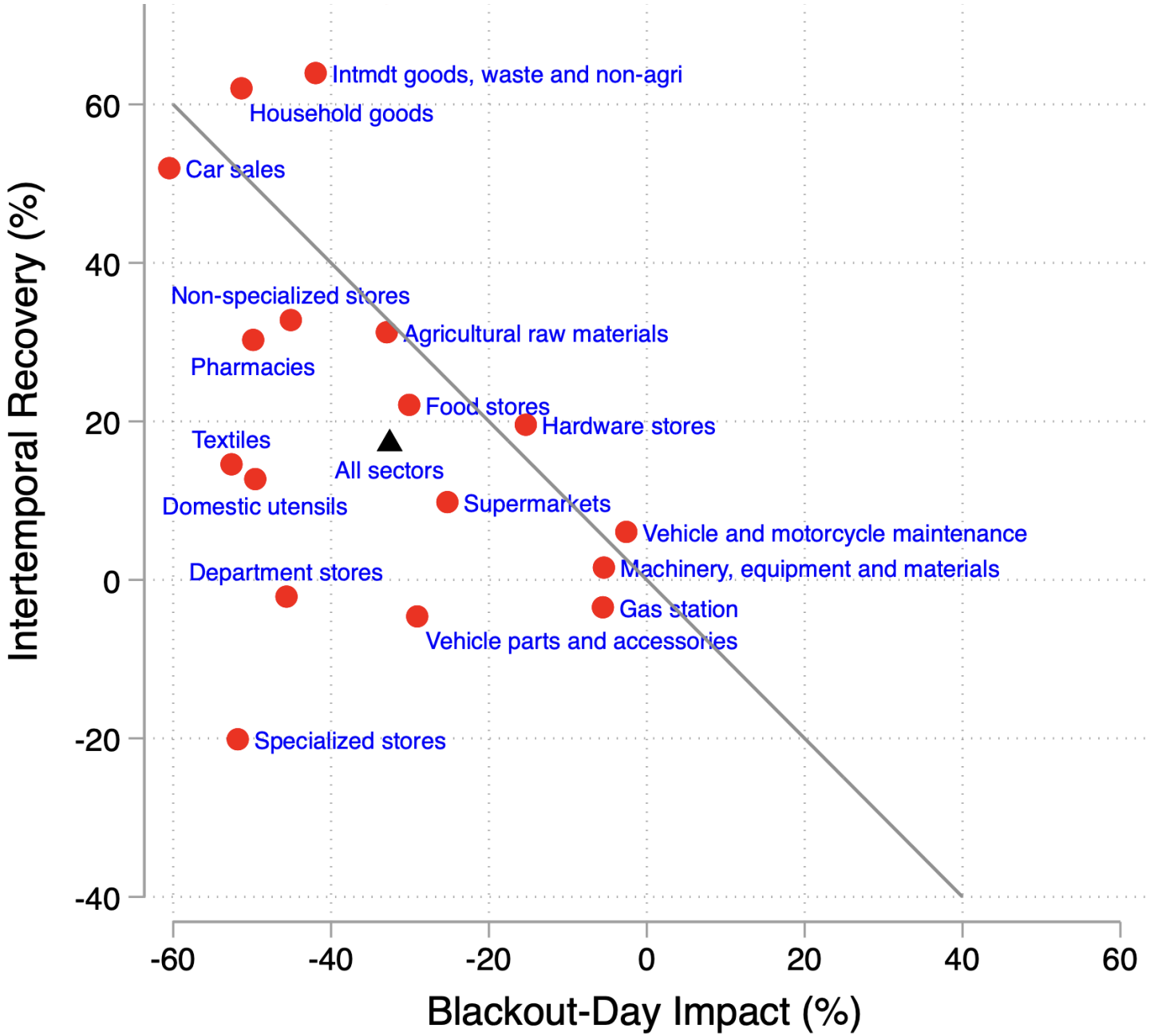
Results 2: Impact by sector

Which sectors had larger blackout-day impacts?



- Each estimate comes from separate regressions by economic sector

Blackout-day impact vs. inter-temporal recover effects



Road map of the talk

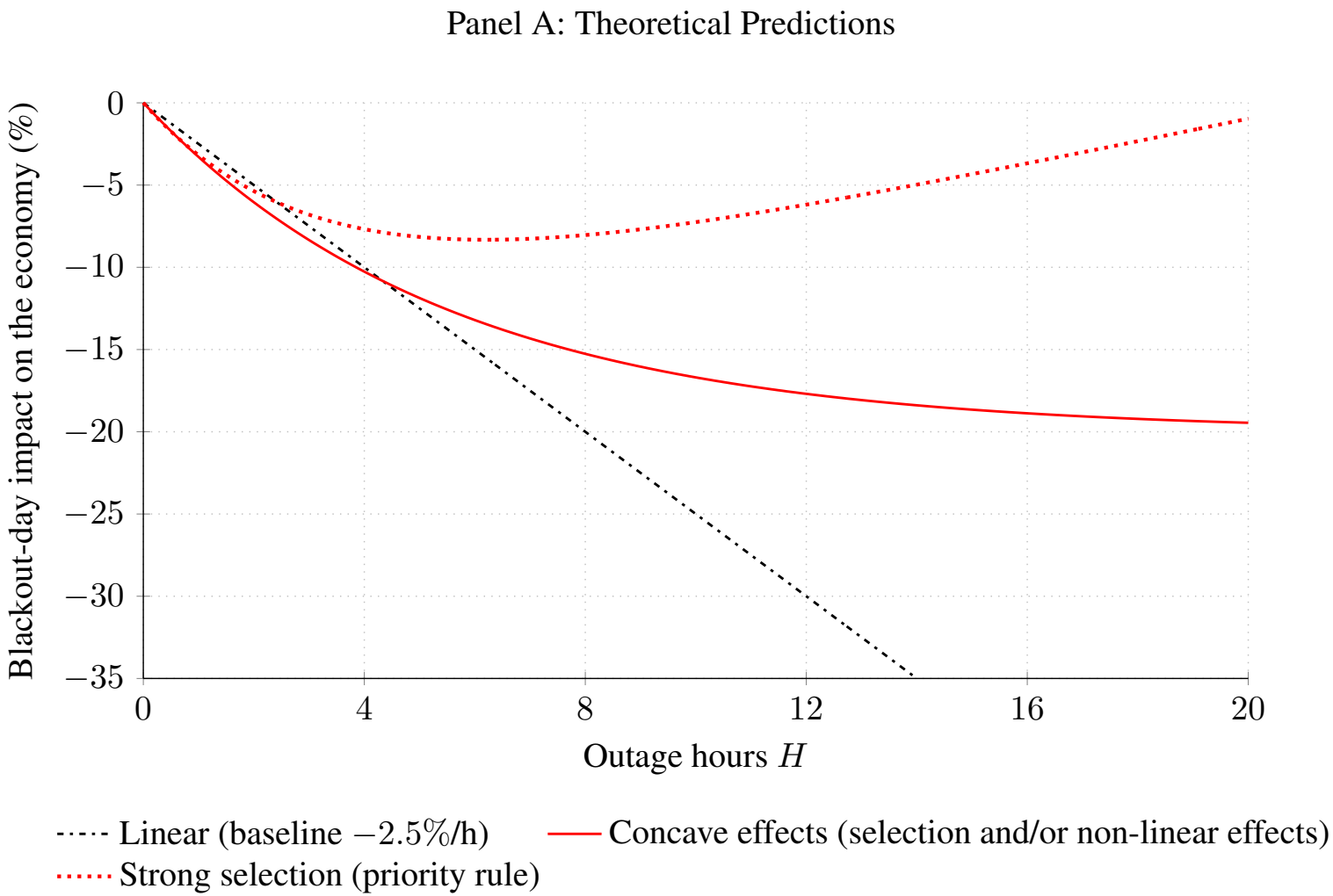
1. Introduction
2. Background and Data
3. Result 1: Aggregate impact
4. Result 2: Impact by economic sector
5. Result 3: Marginal effect of lost load

Results 4: Marginal effect of lost load

Can we use spatial variation to estimate a marginal effect?

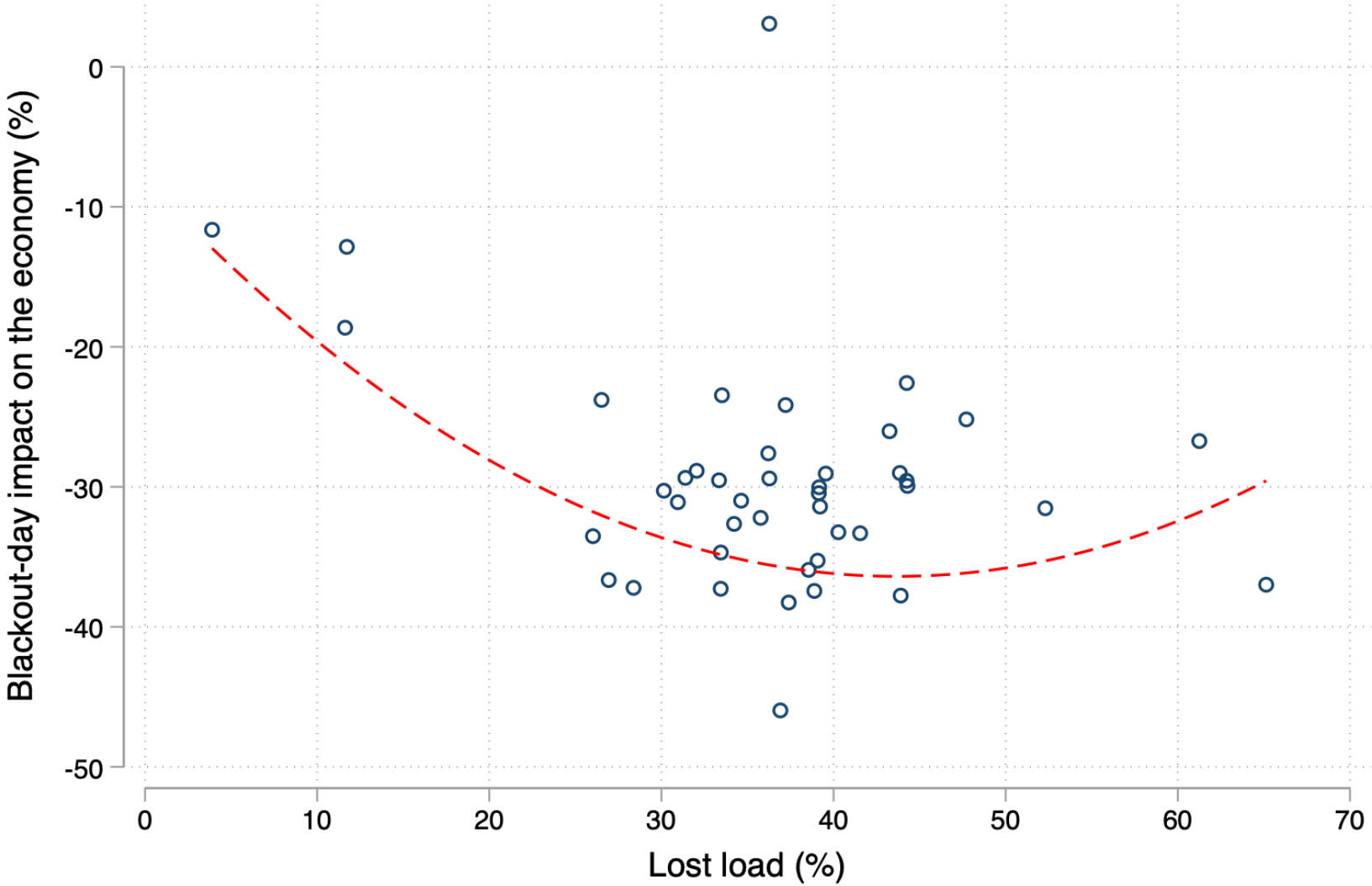
- So far, we focused on the nationwide impact
- There is spatial variation in the severity of blackouts
- Can we use this variation to estimate the marginal effect of lost load?

Challenge: Hours of blackouts are likely to be endogenous



- Regulators might prioritize recovery in "high impact" (higher β_i) regions
- This selection on gain biases OLS and may generate a U-shaped curve

Indeed, we empirically observe that pattern in the data



- Binscatter plot of comuna-level black-day impacts (%) against lost load (%)

Instruments

1. IV_1: Distance from Coquimbo (the origin of the grid failure)
   - We calculate distance from each comuna to Coquimbo

2. IV_2: Supply loss (reductions in electricity generation) in local region
   - We use hourly generation data at the power plant unit level
   - Define supply loss relative to the day before

Marginal effects of hourly blackouts

Dependent variable: Black-out day impact on the economy (%)				
	(1)	(2)	(3)	(4)
Lost load (%)	-0.078	-1.877	-1.680	-1.788
	(0.093)	(0.851)	(0.846)	(0.620)
Constant	-32.227	34.131	26.847	30.849
	(3.525)	(31.863)	(31.586)	(23.463)
Estimation	OLS	IV	IV	IV-GMM
Instruments		Distance	Supply loss	Both
First stage F-stat		23.49	20.16	14.78
Mean of dep. var.	-29.14	-29.14	-29.14	-29.14
Observations	308	308	308	308

- IV_1: Distance from Coquimbo (the origin of the grid failure)
- IV_2: Supply loss (reductions in electricity generation) in local region
- Interpretation: A percentage point increase in lost load leads to a ≈ 1.788 percentage point decline in economic activity

We study how nationwide blackouts affect the economy

1. Integrate data from 1) Electricity market and 2) Central Bank of Chile
   - Hourly electricity demand data at the node-level
   - Hourly electricity supply data at the power plant unit level
   - Administrative tax records on daily retail sales
   - Transbank data: retail & wholesale transactions by credit, debit, POS

2. Estimate 1) blackout-day impact and 2) inter-temporal recovery effect
   - Blackout-day impact: -35% on economic activity
   - Inter-temporal recovery effect: $+15\%$ on economic activity
   - Heterogeneity by sector both in the impact and intertemporal recovery
   - Important b/c most studies and policy discussions ignore recovery effects

3. Aim to provide valuable insights for the Value of lost load (VoLL)

Thank you! 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

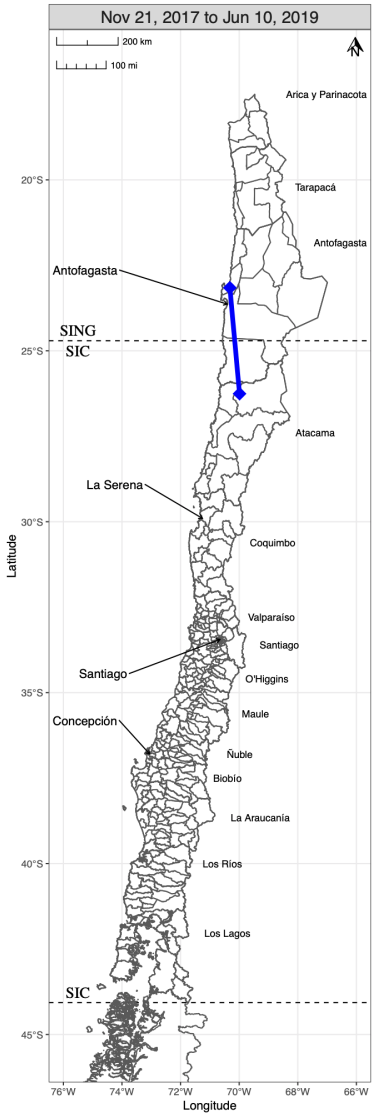


Figure: SING-SIC interconnection.

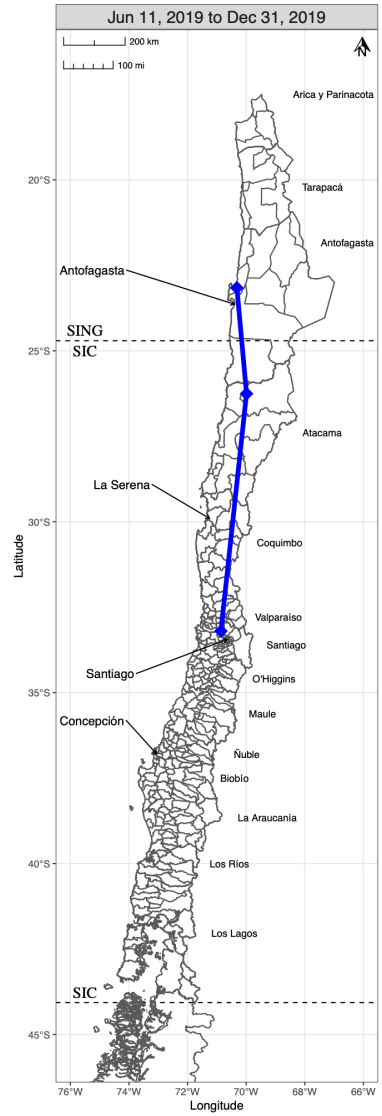


Figure: SEN system

Commune Coquimbo: The origin of the collapse

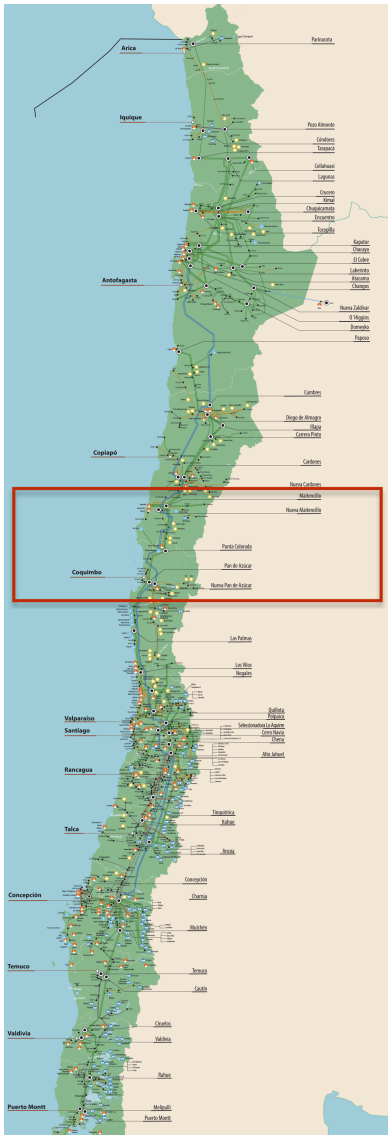


Figure: SEN electric system map.

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