The Dynamic Impact of Market Integration: Evidence from Renewable Energy Expansion in Chile

Gonzales et.al (2023), Econometrica

Enviromental Reading Group session 11

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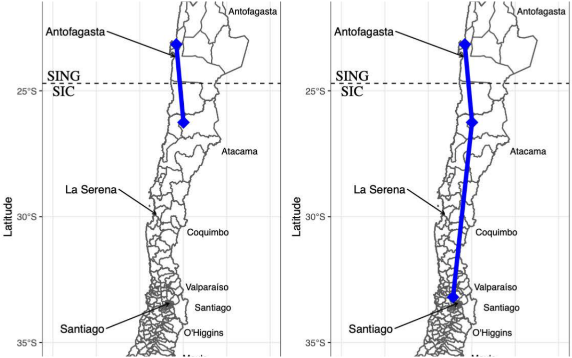
Motivation and Research Question

- Electricity markets are segmented, even within a country. This disconnection results in price differentiation among areas, which could cause production inefficiency and impede renewable investments.
- This paper looks at power market integration in Chile to show whether and if so, to what degree, market integration reduces production cost and encourages solar PV investment.
- Dynamic trade model that incorporates anticipated investment.

Interconnection

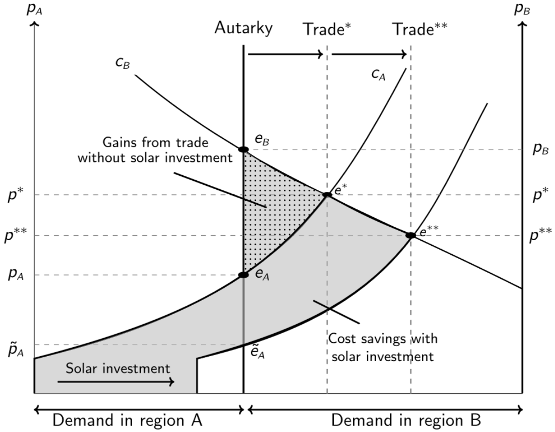


- Before 2017, two separate markets: SING, SIC (solar abundant area)
- 2014: Announcement (shock)
- 2017 Nov: Interconnection
- 2019 June: Reinforcement

Contribution

- Empirical results.
- Dynamic effect (investment).

A Static Trade Model



Equilibrium

- Autarky:

$$p^N = \beta^N D^N, q^N = D^N, p^S = \beta^S D^S, q^S = D^S \tag{1}$$

- Integration+Static:

$$p^* = \frac{\beta^N \beta^S}{\beta^N + \beta^S} D, q^N = \frac{\beta^S}{\beta^N + \beta^S} D, q^S = \frac{\beta^N}{\beta^N + \beta^S} D \tag{2}$$

- Integration+Dynamic:

$$q^{solar} = D - \frac{\beta^N + \beta^S}{\beta^N \beta^S} c, p^{**} = c \tag{3}$$

Equilibrium with Expectation

Investment is based on expectation of integration, not actual integration. However, interaction does not happen at the time of investment. Hence, a dynamic autarky equilibrium:

$$p^N = (1 + \frac{\beta^N}{\beta^S})c - \beta^N D^S < c, \tag{4}$$

$$q^N = \frac{\beta^N + \beta^S}{\beta^N \beta^S} c - D^S, \tag{5}$$

$$p^S = \beta^S D^S, q^S = D^S \tag{6}$$

Question: We observe this in data, which is explained by competing in obtaining permit and constructions. But it is not rational to construct much earlier than actual interconnection date. Moreover, old and new solar assets have the same right.

Observations I

OBSERVATION 1: In the presence of investment anticipation or delay, gross cost savings from a grid expansion will be underestimated around the event window. Furthermore, net cost benefits accounting for the investment costs of solar will be

- underestimated if expansion is delayed, and
- overestimated if expansion is anticipated but its investment costs are ignored.

Observations II

OBSERVATION 2: In the presence of investment anticipation or delay, **price reductions** from a grid expansion will be underestimated around the event window.

Observations III

OBSERVATION 3: In the presence of investment anticipation or delay, reductions in **regional price differences** (price convergence) around the event window will be

- overestimated in the presence of anticipation,
- correct in the presence of delayed investment as long as prices converge both with and without investment. Otherwise, price convergence will be overestimated.

Data

Chile power market:

- cost-based dispatch (not market-based)
- Hourly and Daily Marginal Cost at the Unit Level, 2014-2019
- Hourly Demand at the Node Level, 2017-2019
- Hourly Market Clearing Prices at the Node Level, 2008-2019
- Hourly Electricity Generation at the Unit Level, 2014-2019
- Plant Characteristics and Investment

Summary Statistics

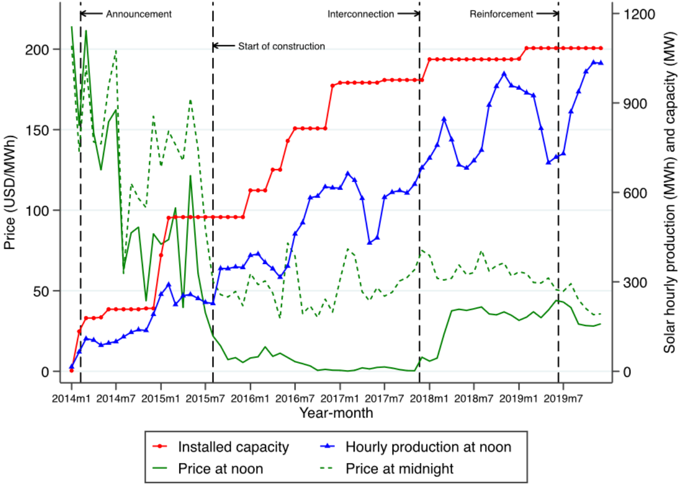
TABLE I

SUMMARY STATISTICS.

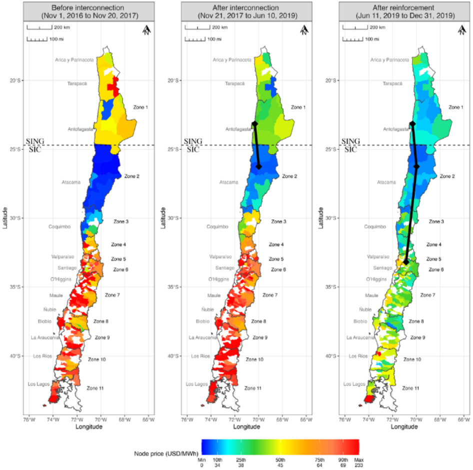
	Pre-Interconnection (Nov. 2016–Nov. 2017)		Post-Interconnection (Nov. 2017–Dec. 2019)
	SIC	SING	SEN
Hourly total generation at noon (MWh)	6851	2135	9349
	(645)	(186)	(647)
Hourly total generation at midnight (MWh)	5900	2241	8482
	(316)	(195)	(351)
Node price at noon (USD/MWh)	54.46	45.14	52.16
	(35.58)	(16.95)	(25.01)
Node price at midnight (USD/MWh)	52.06	71.66	54.82
	(24.9)	(35.26)	(20.94)
Variable cost: Thermal (USD/MWh)	44.67	42.94	43.73
	(17.28)	(11.12)	(15.08)
Installed capacity (MW)			
Hydro	6225	16	6304
Solar	1315	603	2500
Thermal	6131	3832	10,385
Wind	1144	194	2009

Note: This table shows the summary statistics of our data. Installed capacity is defined as the 99th percentile of hourly generation.

Investment Anticipation in Atacama



Node Price Convergence



- Extreme low price in Atacama because of investment anticipation.
- Price in Antofagasta and Atacama converge after interconnection.

Generation Cost Reduction

$$c_t = \beta_1 I_t + \beta_2 R_t + \beta_3 X_t + \theta_m + u_t \tag{7}$$

- c_t: observed merit-order cost
- c_t^*: One of control variables in vector X_t, nationwide merit-order cost
- $c_t \neq c_t^*$:
  - plants go offline for maintenance.
  - plants are forced to shut down.
  - grid congestion, transmission constraint.

Generation Cost Reduction

TABLE II

EVENT STUDY ANALYSIS OF GENERATION COST (WITHOUT INVESTMENT EFFECTS).

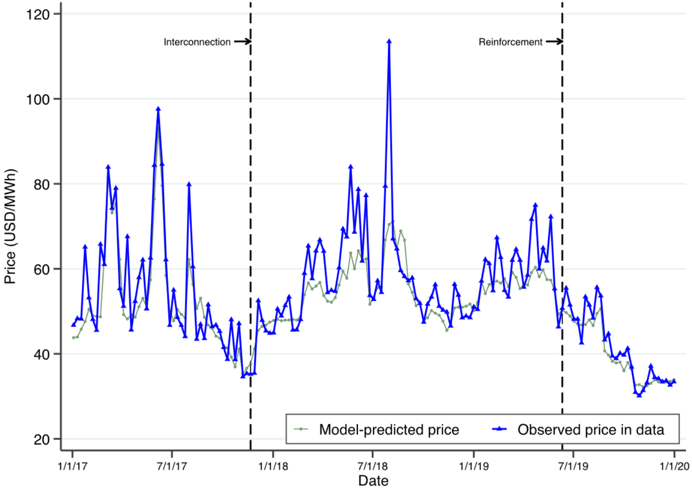
	Hour 12				All Hours			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1(After the interconnection)	−2.75	−2.48	−2.51	−2.42	−2.16	−2.15	−2.15	−2.07
	(0.20)	(0.27)	(0.27)	(0.26)	(0.15)	(0.17)	(0.17)	(0.17)
1(After the reinforcement)	−1.20	−1.13	−1.32	−0.96	−1.09	−0.63	−0.64	−0.62
	(0.20)	(0.55)	(0.58)	(0.58)	(0.14)	(0.35)	(0.37)	(0.37)
Nationwide merit-order cost	1.08	1.10	1.10	1.12	1.01	1.02	1.02	1.03
	(0.02)	(0.03)	(0.02)	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)
Coal price [USD/ton]		−0.03	−0.03	−0.03		−0.01	−0.01	−0.01
		(0.01)	(0.01)	(0.01)		(0.01)	(0.01)	(0.01)
Natural gas price [USD/m^3]			−9.92	−10.27			−0.37	−0.55
			(4.32)	(4.33)			(3.12)	(3.10)
Hydro availability				0.43				0.00
				(0.14)				(0.00)
Scheduled demand (GWh)				−0.51				−0.01
				(0.13)				(0.00)
Sum of effects	−3.95	−3.61	−3.83	−3.38	−3.24	−2.78	−2.78	−2.68
Mean of dependent variable	35.44	35.44	35.44	35.44	38.63	38.63	38.63	38.63
Month FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Sample size	1033	1033	1033	1033	1033	1033	1033	1033
R^2	0.92	0.94	0.94	0.94	0.95	0.97	0.97	0.97

Constrained Optimization Problem: Short-term Dispatch

$$
\begin{aligned}
&\min_{q,imp,exp} \sum_{z,t,j} C_{ztj}(q_{ztj}) \\
&s.t. \sum_j q_{ztj} + \sum_j ((1-\delta_1)\text{imp}_{lzt} - \text{exp}_{lzt}) \geq \frac{D_{zt]}}{1-\delta_2}, \forall z, t, \\
&0 \leq \text{imp}_{lzt} \leq f_{lz}, \quad 0 \leq \text{exp}_{lzt} \leq f_{lz}, \forall l, z, t, \\
&\sum_z (\text{imp}_{lzt} - \text{exp}_{lzt}) = 0, \forall l, t
\end{aligned} \tag{8}
$$

Some more capacity constraints.

Goodness-of-Fit

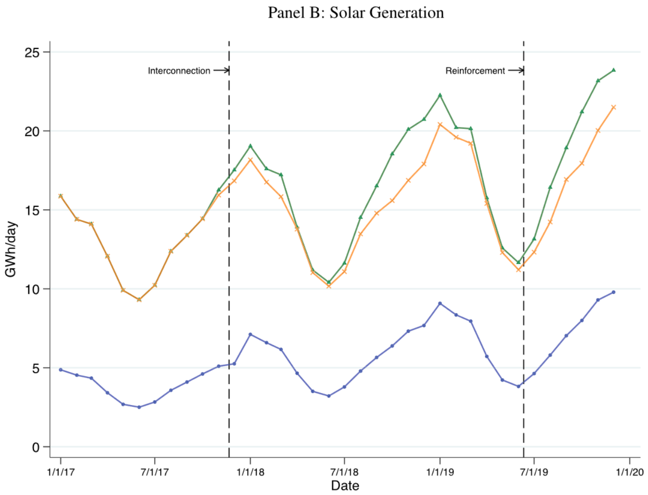


Free Entry

$$E\left[\sum_{y\in Y}\frac{\sum_h p_{zyh}(k)\times q_{zyh}(k)}{(1+r)^y}\right]=c_z k_z,\forall z, \tag{9}$$

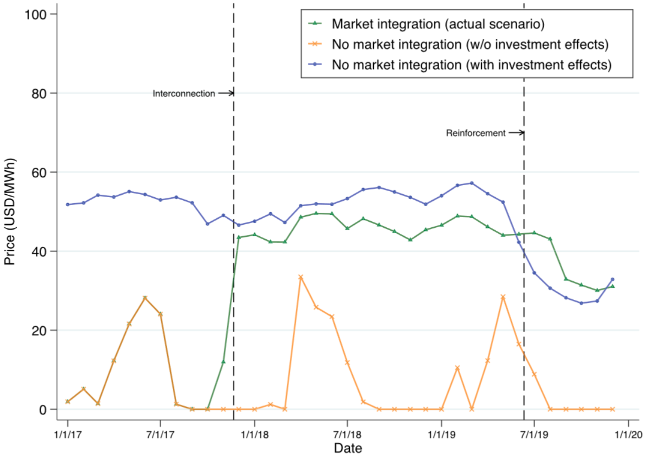
- By observed investment level and equlibrium from dispatch model, assuming $|Y|=25, r=0.0583$, the cost $c_1=\$1.84m/MW, c_2=\$1.67m/MW$.
- zone 1: Antofagasta, zone 2: Atacama.

Counterfactual Simulation



Counterfactual Simulation

Panel A: Prices in Atacama (Renewable-Intensive Region)



Cost-Benefit Analysis

TABLE V

COST-BENEFIT ANALYSIS OF TRANSMISSION INVESTMENTS.

	(1)	(2)
Modelling assumptions		
Investment effect due to lack of integration	No	Yes
Benefits from market integration (million USD/year)		
Savings in consumer cost	176.3	287.6
Savings in generation cost	73.4	218.7
Savings from reduced environmental externality	−161.4	249.4
Increase in solar revenue	110.7	183.5
Costs from market integration (million USD)		
Construction cost of transmission lines	1860	1860
Cost of additional solar investment	0	2522
Years to have benefits exceed costs		
With discount rate = 0	14.8	6.1
With discount rate = 5.83%	>25	7.2
With discount rate = 10%	>25	8.4
Internal rate of return		
Lifespan of transmission lines = 50 years	6.95%	19.67%
Lifespan of transmission lines = 100 years	7.23%	19.67%

Wrap-Up

- This paper studies quantitatively the impact of Chilean market integration on production efficiency and renewable investment.
- Consistent with stylized trade model. Integration, grid expansion results in price convergence and lower generation costs and emissions.
- Ignoring investment effects would substantially underestimate the benefits of market integration.

Reference

Gonzales, L. E., Ito, K., & Reguant, M. (2023). The Investment Effects of Market Integration: Evidence From Renewable Energy Expansion in Chile. Econometrica, 91(5), 1659-1693.