Shaken Markets:

Natural Disasters and Market Integration

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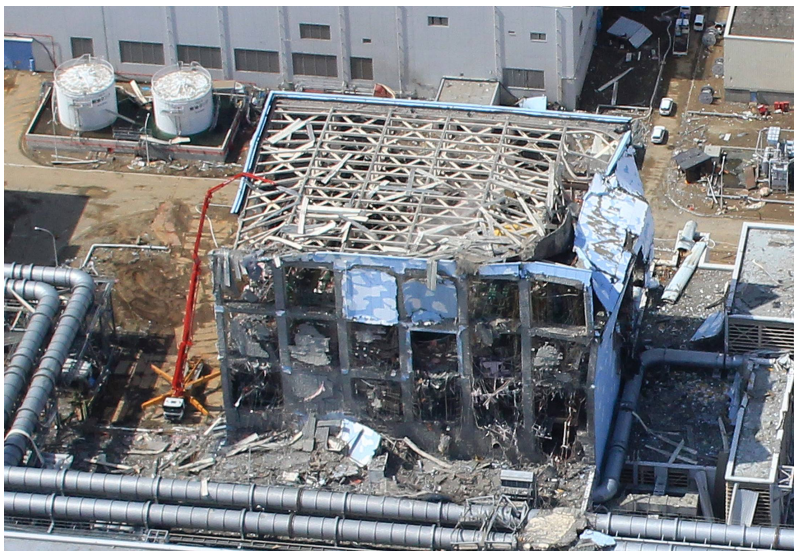
Natural disasters cause disruptions in electricity markets

- Earthquakes (e.g., Great east Japan earthquake in 2011)
- Winter storms (e.g., Texas power crisis in 2021)
- Hurricanes, flooding, and etc.



Does Market Integration Alleviate or Intensify Shocks?

- Some argue that market integration could mitigate shocks
  - Fukushima nuclear crisis in 2011: west part of Japan could have exported more inexpensive supply to east if east-west were more integrated
  - Texas crisis in 2021: other parts of the US could have exported more inexpensive supply to Texas if grids were more integrated

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  - Integration could make a shock to a marginal plant in a particular region relevant to an entire integrated market
  - Impacts on consumers are localized in a closed market but extended in an integrated market

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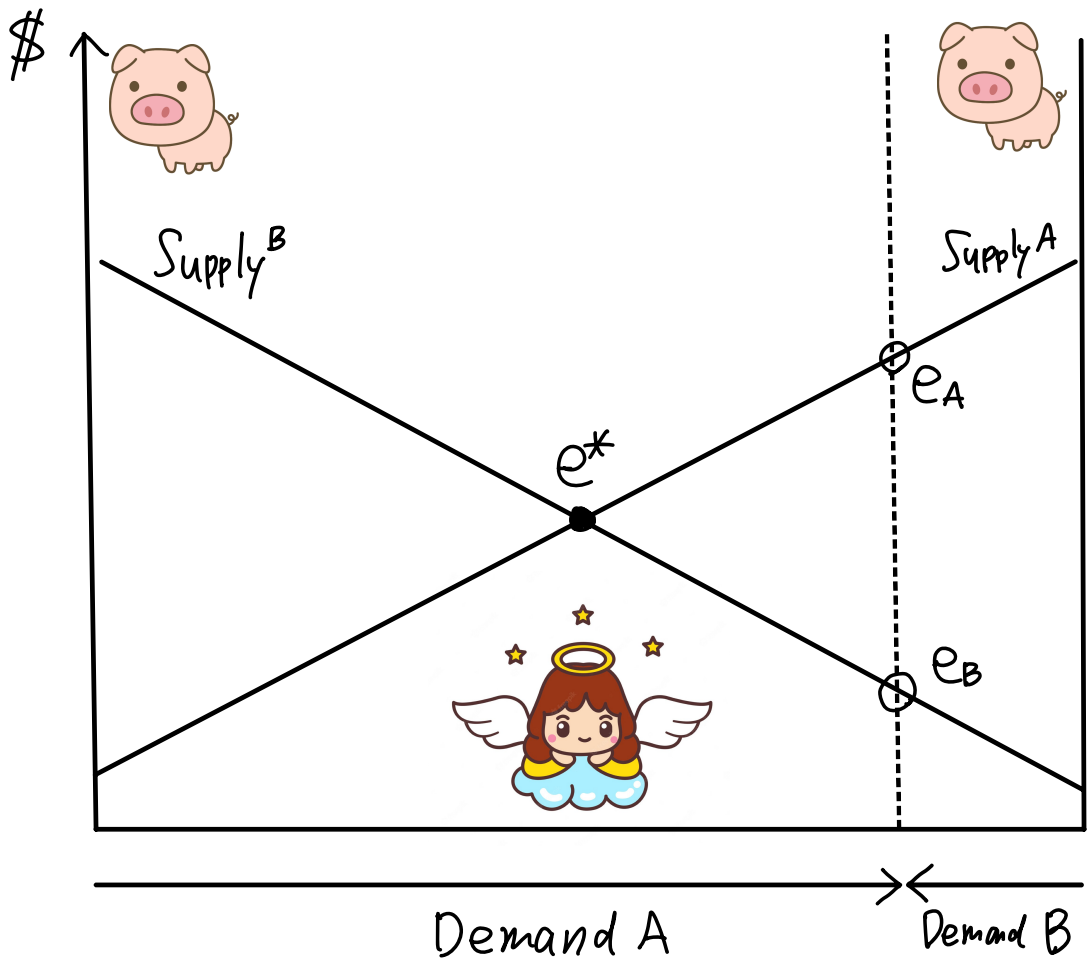
- Maybe, the answer to this question is not obvious?
  - While standard theory tells us overall gains from trade, how integration mitigate/intensify shocks is unclear & understudied?

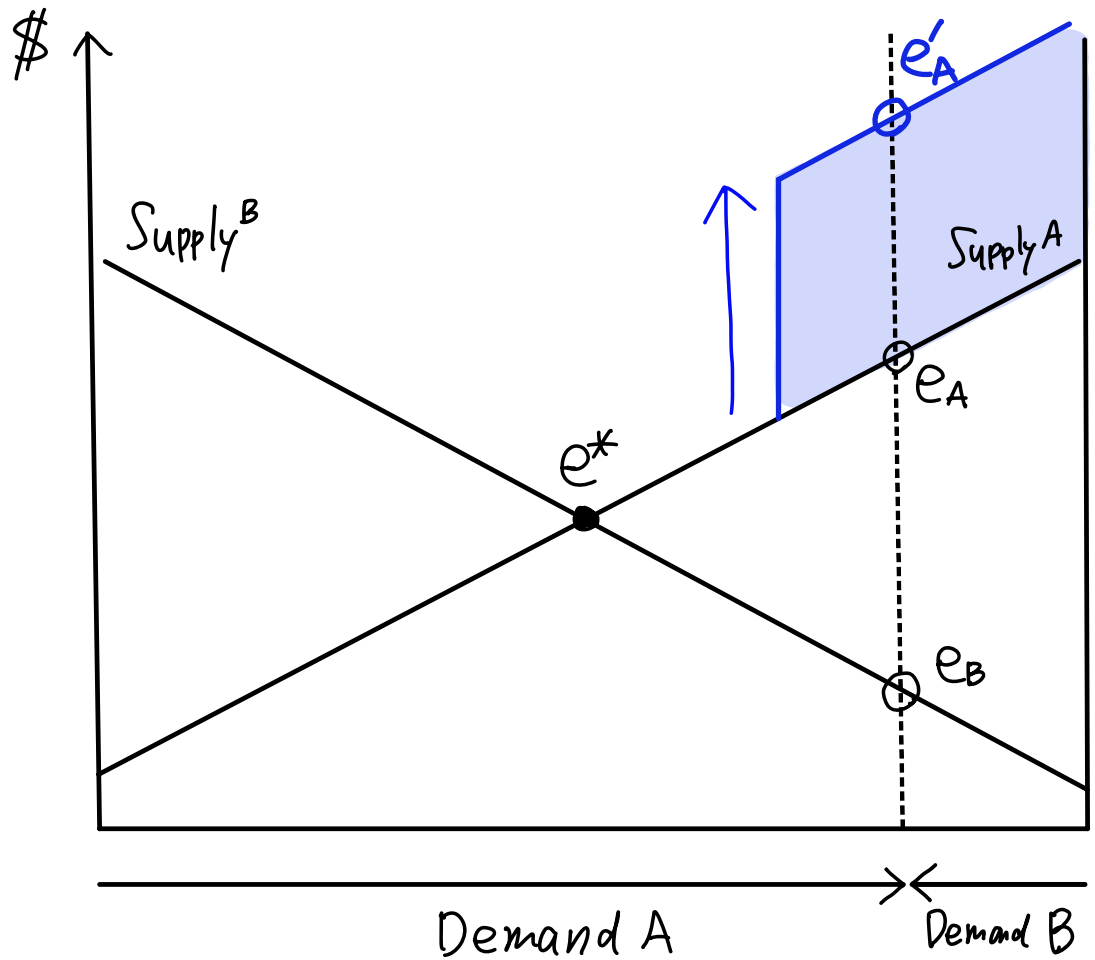
Does Market Integration Alleviate or Intensify Shocks?

Energy camp style hand-writing analysis



Does Market Integration Alleviate or Intensify Shocks?

1. Shocks to generation cost
   - Consider a shock to marginal plants in market A
   - In this case, integration alleviates the shock



Does Market Integration Alleviate or Intensify Shocks?

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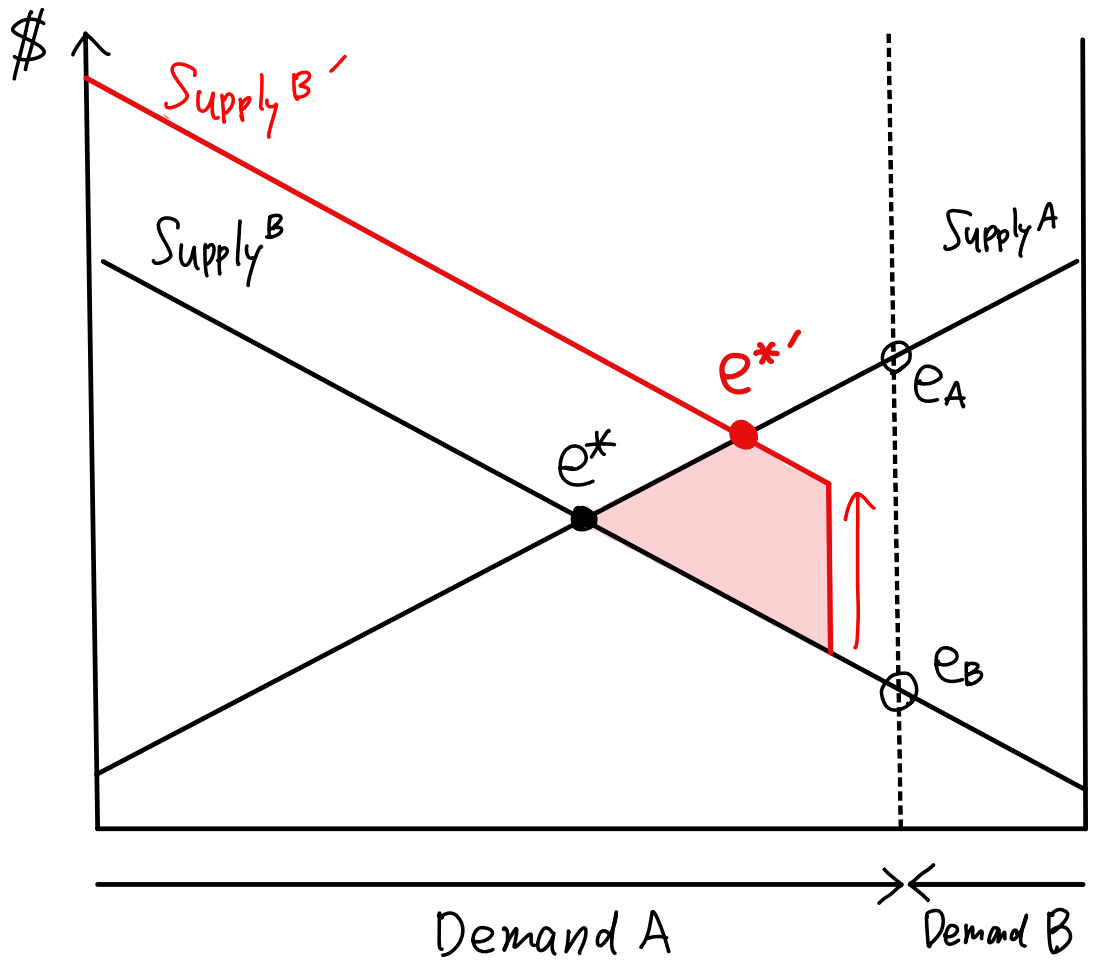

Does Market Integration Alleviate or Intensify Shocks?

2. Shocks to consumer cost
   - Integration softens shocks to consumers in affected regions
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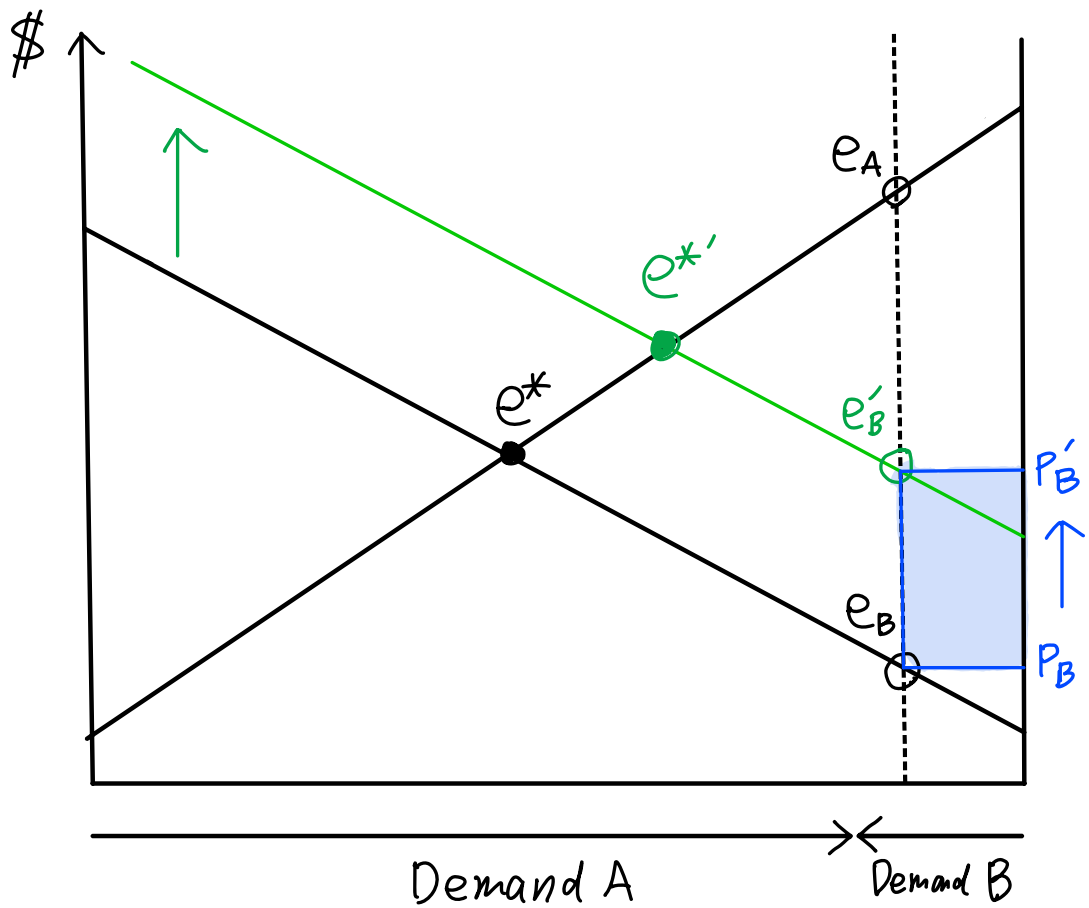
   - The net effect on consumer cost is ambiguous



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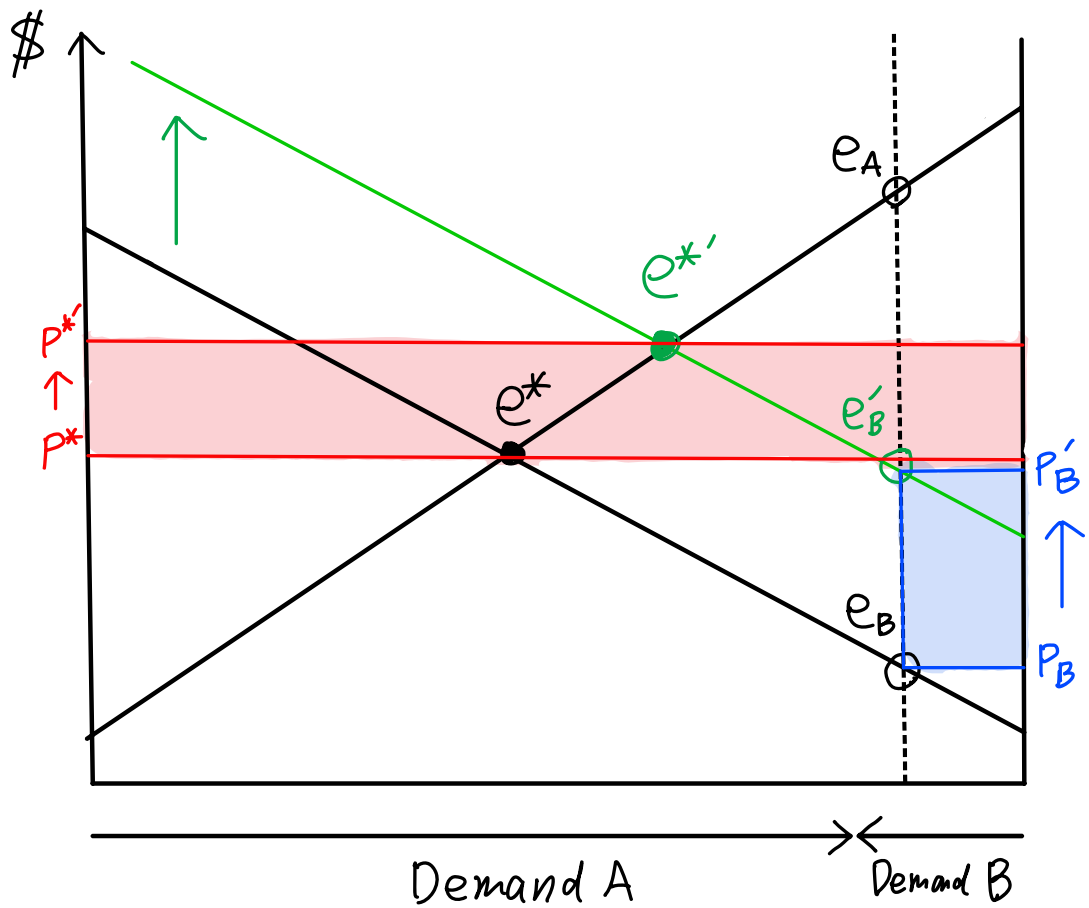
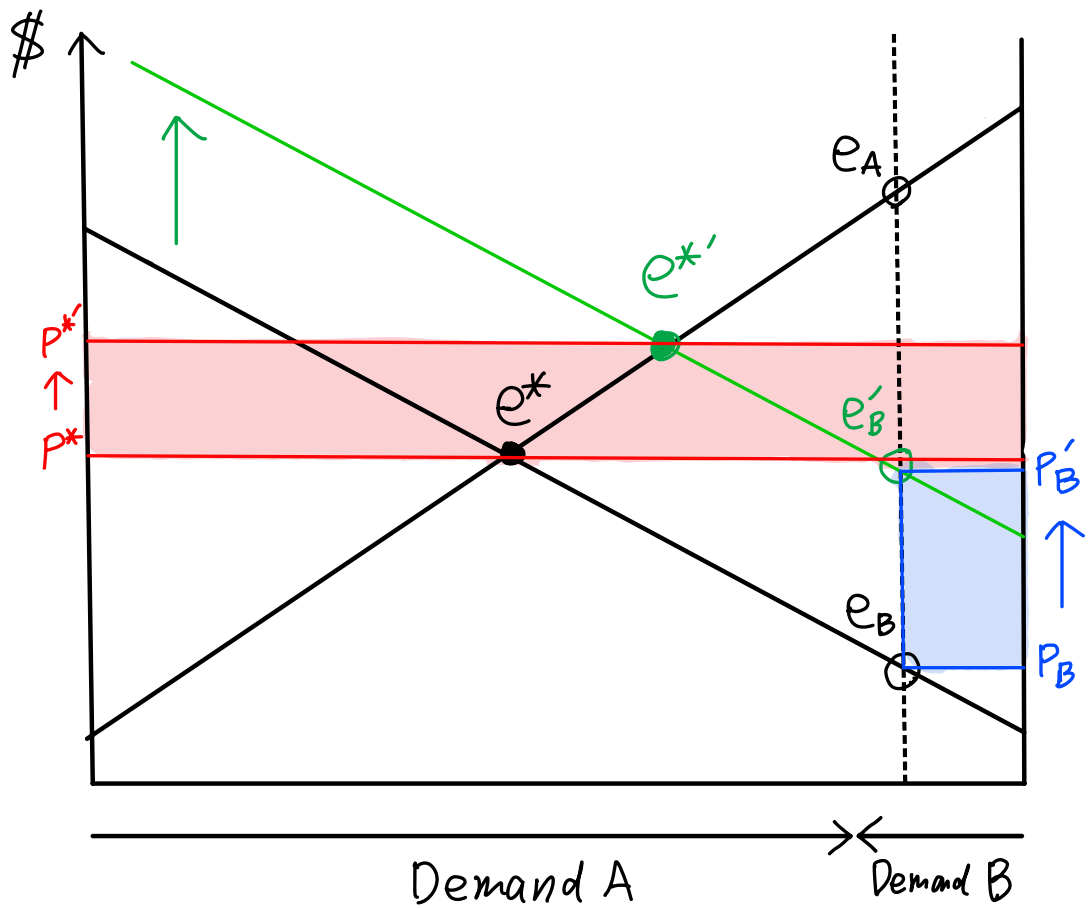


Does Market Integration Alleviate or Intensify Shocks?

3. Shocks to consumer cost (when shocks occur stochastically)
   - One-time shock could make winners & losers from integration
   - But if shocks happen stochastically in different locations (e.g., earthquakes), integration can create risk-sharing?



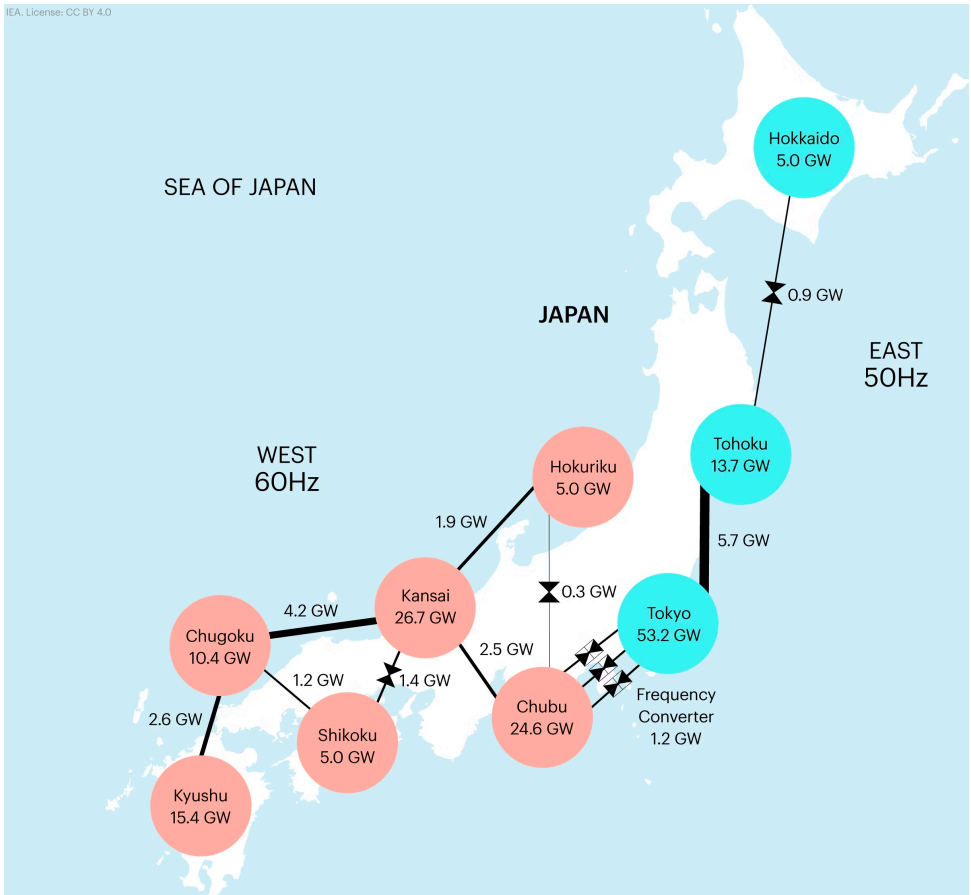
This project uses data from Japan to study this question

1. Natural disaster data (earthquakes, storms, etc.)

2. Wholesale electricity market data
   - Planned and unplanned outages at the unit level
   - Hourly supply and demand
   - Half-Hourly spot market price

$\rightarrow$ Data from Japan provide several useful features for this research question

1) Variation in interconnection capacities & simpler grid



- In 1895, west regions imported turbines from US (60Hz) & east regions imported from Germany (50Hz) $\rightarrow$ resulted in a 50-60Hz system
- Also, historically regional utilities have under-invested interconnections
- Map shows interconnection capacity and max demand in each zone

Frequency converters in Shizuoka prefecture

2) Frequent natural disasters

- Every year, there are many major and smaller earthquake events
- Every year, there are roughly 25 typhoons (hurricanes)
- We observe 1757 natural disaster-related unplanned plant outages in our sample period (2016-current)

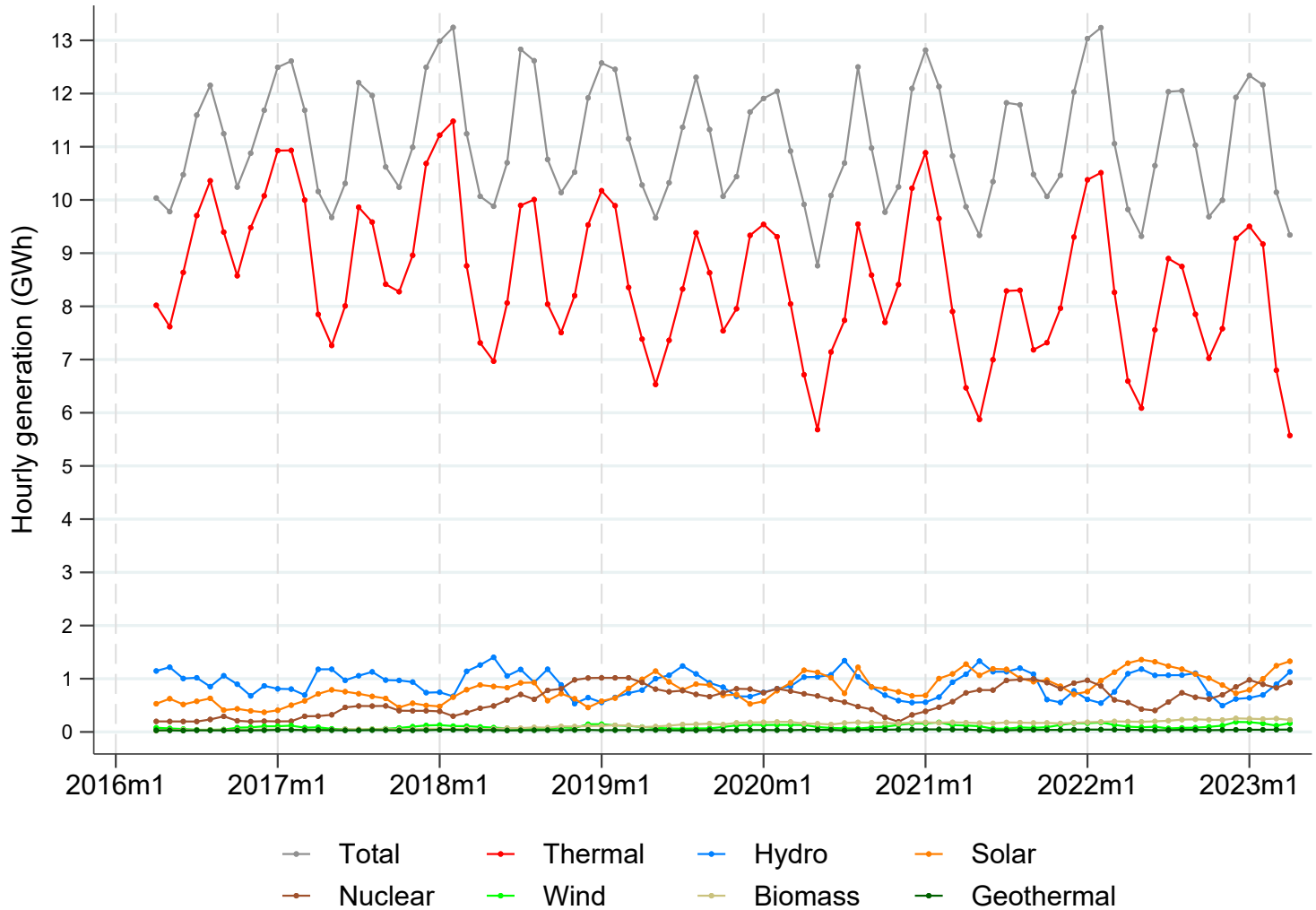
Table: Earthquake counts at the zone level (2016-2020)

	Max Seismic Intensity							
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	Total
1. Hokkaido	403	476	183	59	16	2	1	1140
2. Tohoku	875	1148	384	110	31	1	1	2550
3. Tokyo	734	859	320	91	35	1	0	2040
4. Chubu	477	516	155	34	5	2	0	1189
5. Hokuriku	49	69	21	6	1	1	0	147
6. Kansai	256	234	85	10	4	1	0	590
7. Chugoku	200	228	96	20	4	2	0	550
8. Shikoku	119	116	44	14	3	0	0	296
9. Kyushu	1128	1285	511	163	44	10	4	3145
Total	4241	4931	1799	507	143	20	6	11647

Institutional details

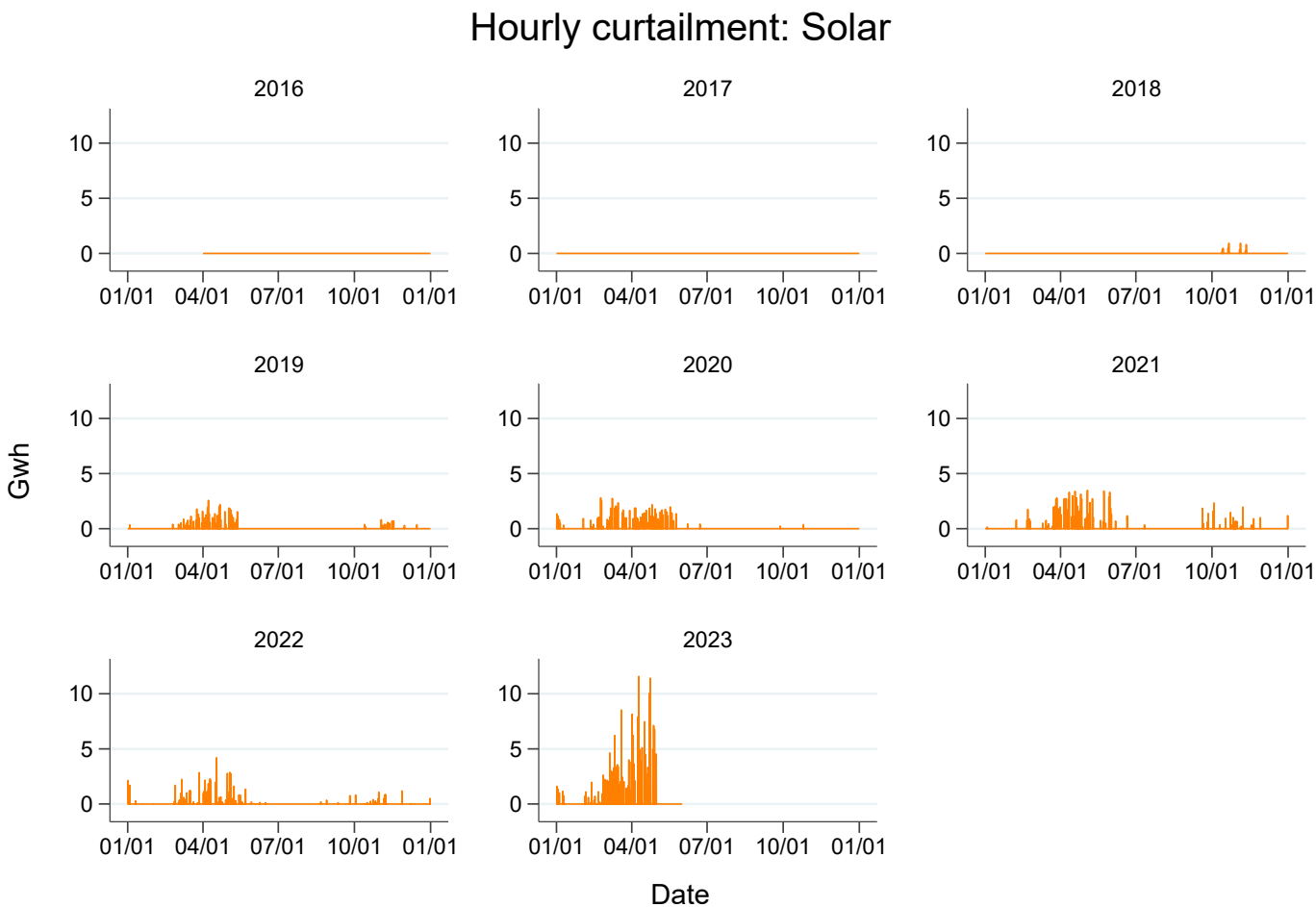
Generation by fuel type

- Roughly, thermal (70%), solar (10%), hydro (10%), nuclear (10%)



Solar curtailment

- Although it's not focus of today's analysis, solar curtailment (reaching 10 GWh) is another reason why market integration is important
- Also, renewable intermittency is another spatially-heterogeneous shocks



Aggregated national level, does not include Okinawa

Japanese wholesale electricity market

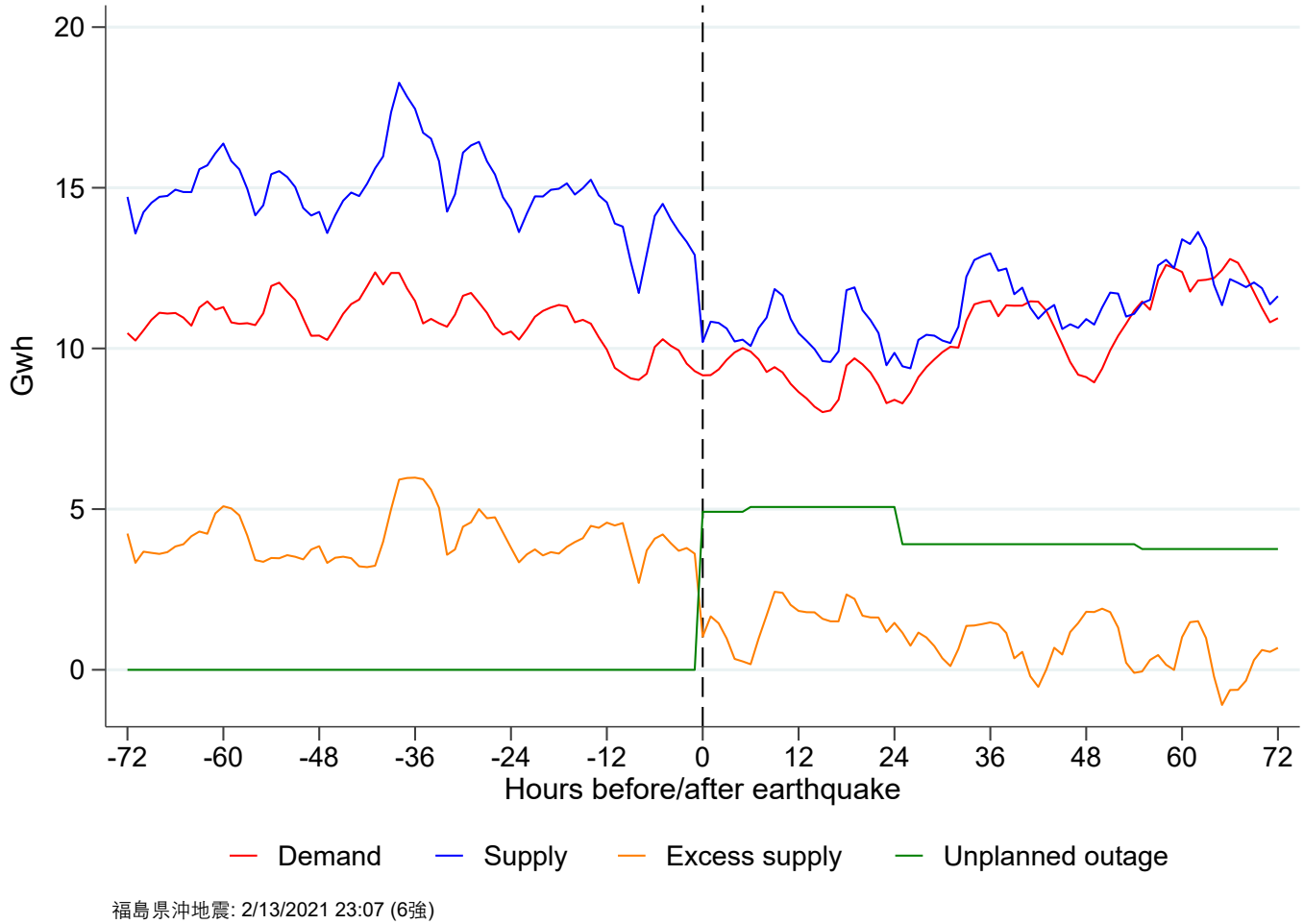
- Japan Electric Power Exchange (JEPX)
  - Forward contracts, day-ahead spot market, and real-time market
  - Day-ahead market at 10 am to clear the next day's 30-min transactions
  - Zonal pricing with the 9 zones shown in the map in previous page
  - Data: day-ahead market zonal prices, bidding curves, etc.

- Organization for Cross-regional Coordination of Transmission Operators (OCCTO)
  - System operator for cross-regional transmission
  - Data: transmission capacity, transmission flows

- Regional Transmission Operators
  - Data: hourly demand and supply

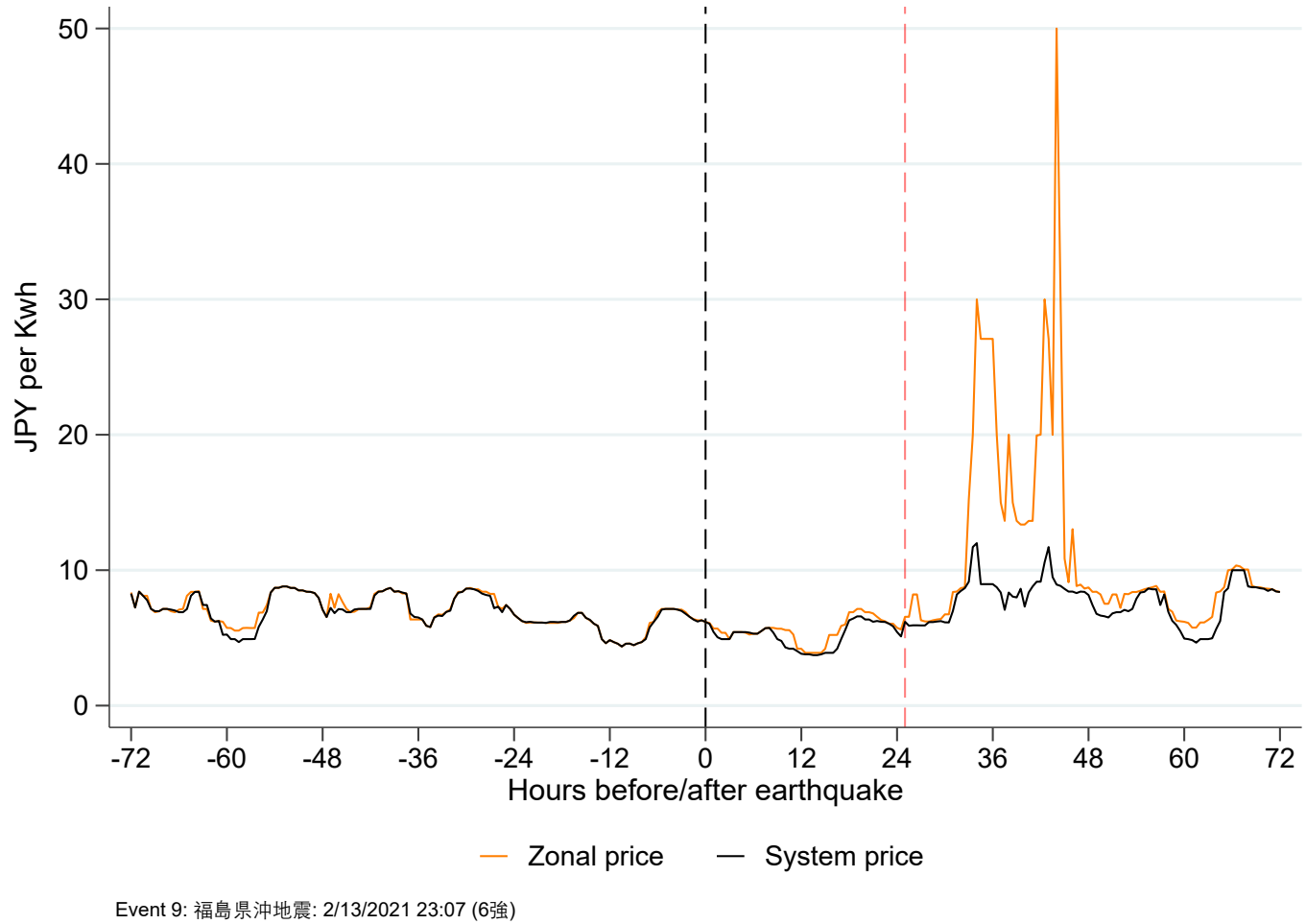
Preliminary analysis and results

Example: Seismic intensity 6 in Tohoku in 2/13/2021



- Demand, supply, excess supply, and unplaned outage in Tohoku
  - Roughly 5 GW capacity was lost
  - Excess supply went down by similar amount

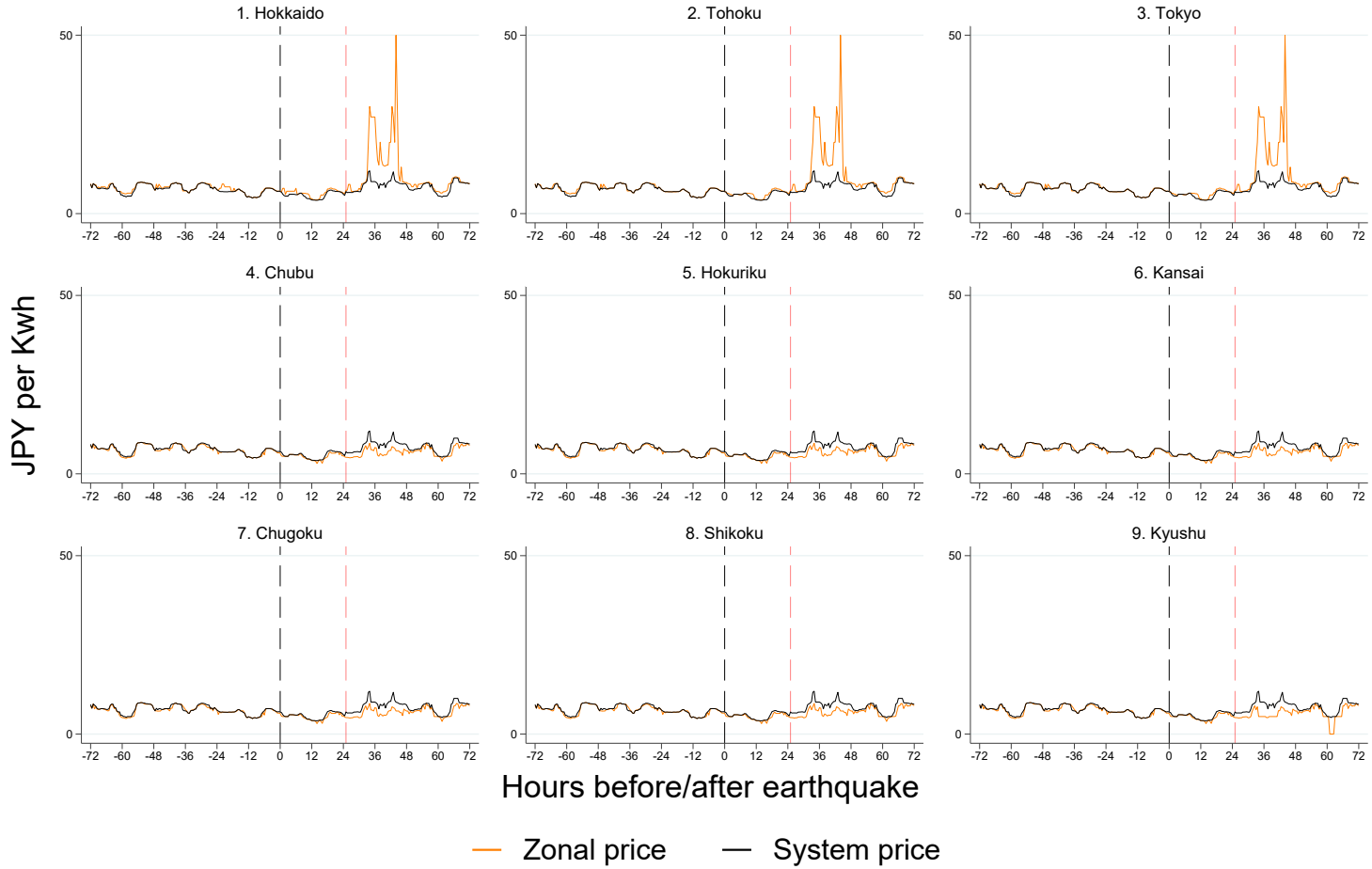
Zonal day-ahead price & counterfactual system price



Event 9: 福島県沖地震: 2/13/2021 23:07 (6強)

- Zonal price in the day-ahead market
- Counterfactual system price (if there was full market integration)
- This suggests the price spikes could have been avoided

Lower-cost supply could not reach Tohoku from west

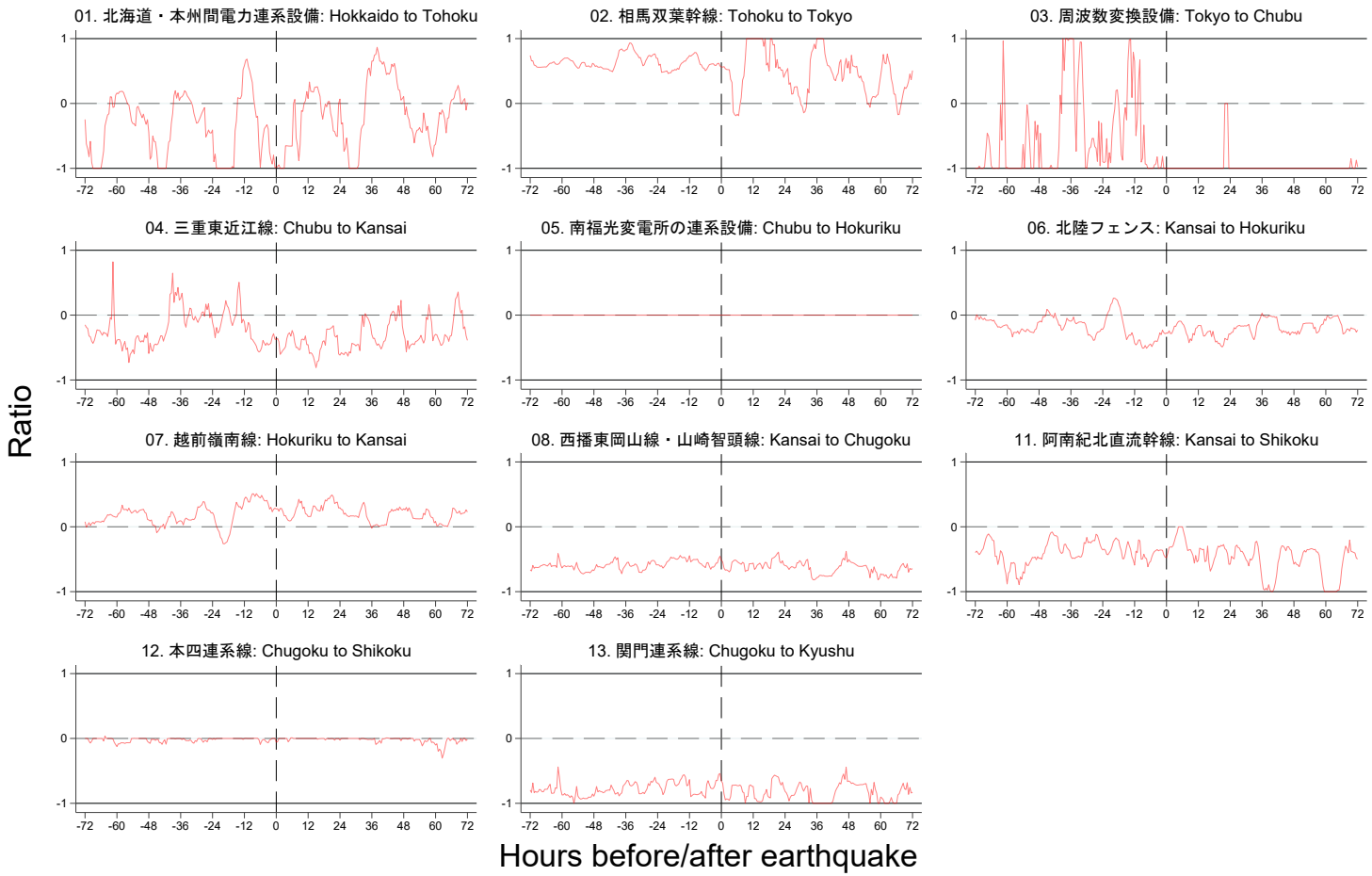


Event 9: 福島県沖地震: 2/13/2021 23:07 (6強)
Main region: Tohoku
Red line: 12am

- Zonal price in the day-ahead market & counterfactual system price
- These figure suggest there were lower-cost supply in west of Tokyo

Bottle necks can be seen in the interconnection flow data

(Hourly interconnection flow/capacity) $\in [-1, 1]$



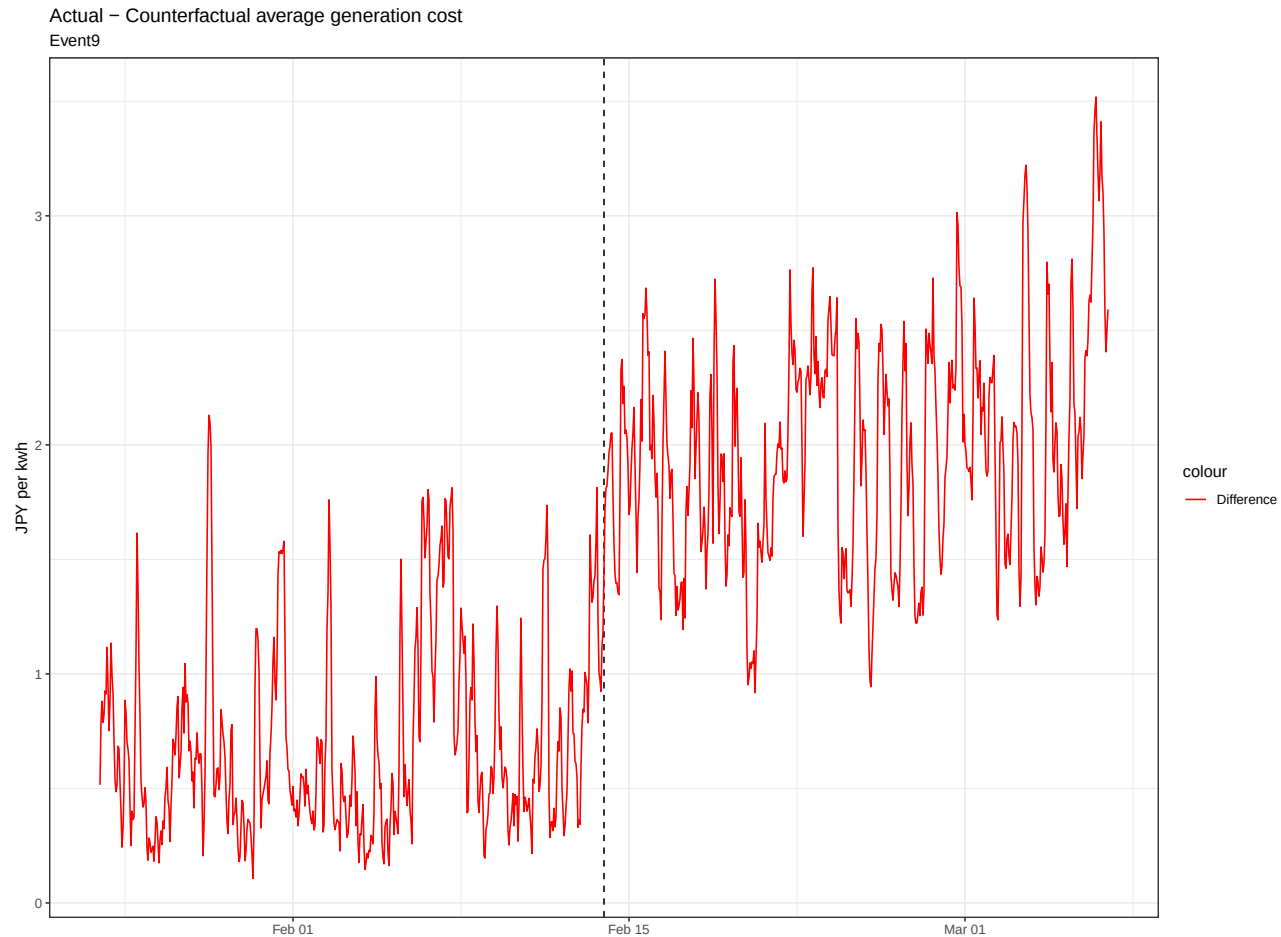
Event 9: 福島県沖地震: 2/13/2021 23:07 (6強)
Planned flow ratio = planned flow / effective capacity
Effective capacity = operation capacity - margin - adjustment
Main region: Tohoku

- In this event, the primary bottleneck was the west-east (Tokyo-Chubu)

Does Market Integration Alleviate or Intensify Shocks?

- Idea: For each of the 1757 natural disaster-related unplanned outage events, compute the "full market integration" counterfactual outcomes
  - This counterfactual solves dispatch with no interconnection congestion
  - We can simulate counterfactuals with other transmission constraints, too
- Compare the actual and counterfactual outcomes
  - Shocks to generation cost
  - Shocks to consumer cost
- Investigate what determines heterogeneity in the integration's impact on natural disaster shocks
  - Characteristics of affected region (demand center or supply center)
  - Marginal vs. infra-marginal plants affected by a disaster
- Today: preliminary results for one example event

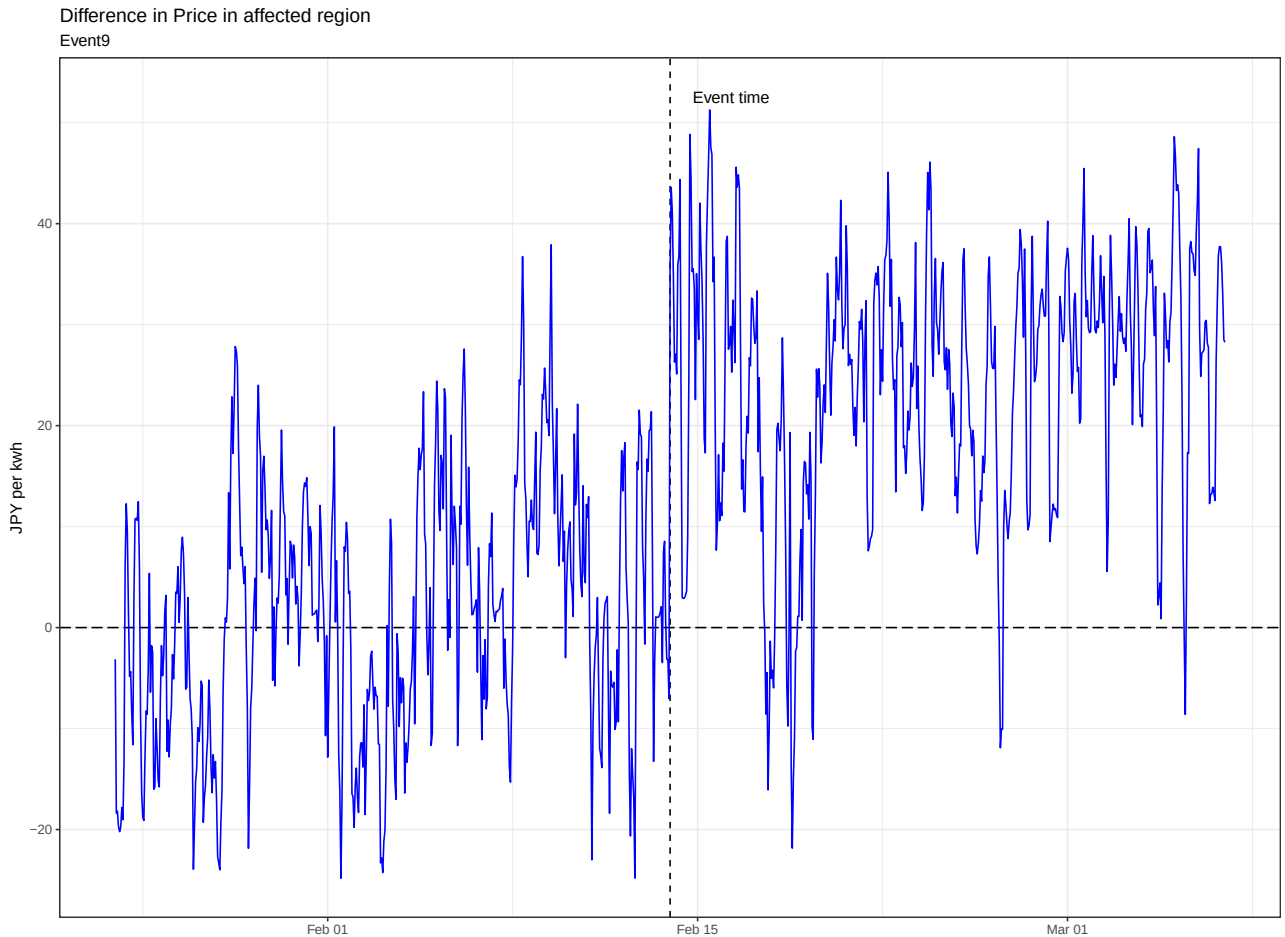
1) ΔGeneration cost = "actual - "full market integration"



- Figure shows Δ(Ave generation cost) = "actual" - "full market integration"
- For this event, integration would have softened shocks to generation cost

2) ΔConsumer cost = "actual - "full market integration"

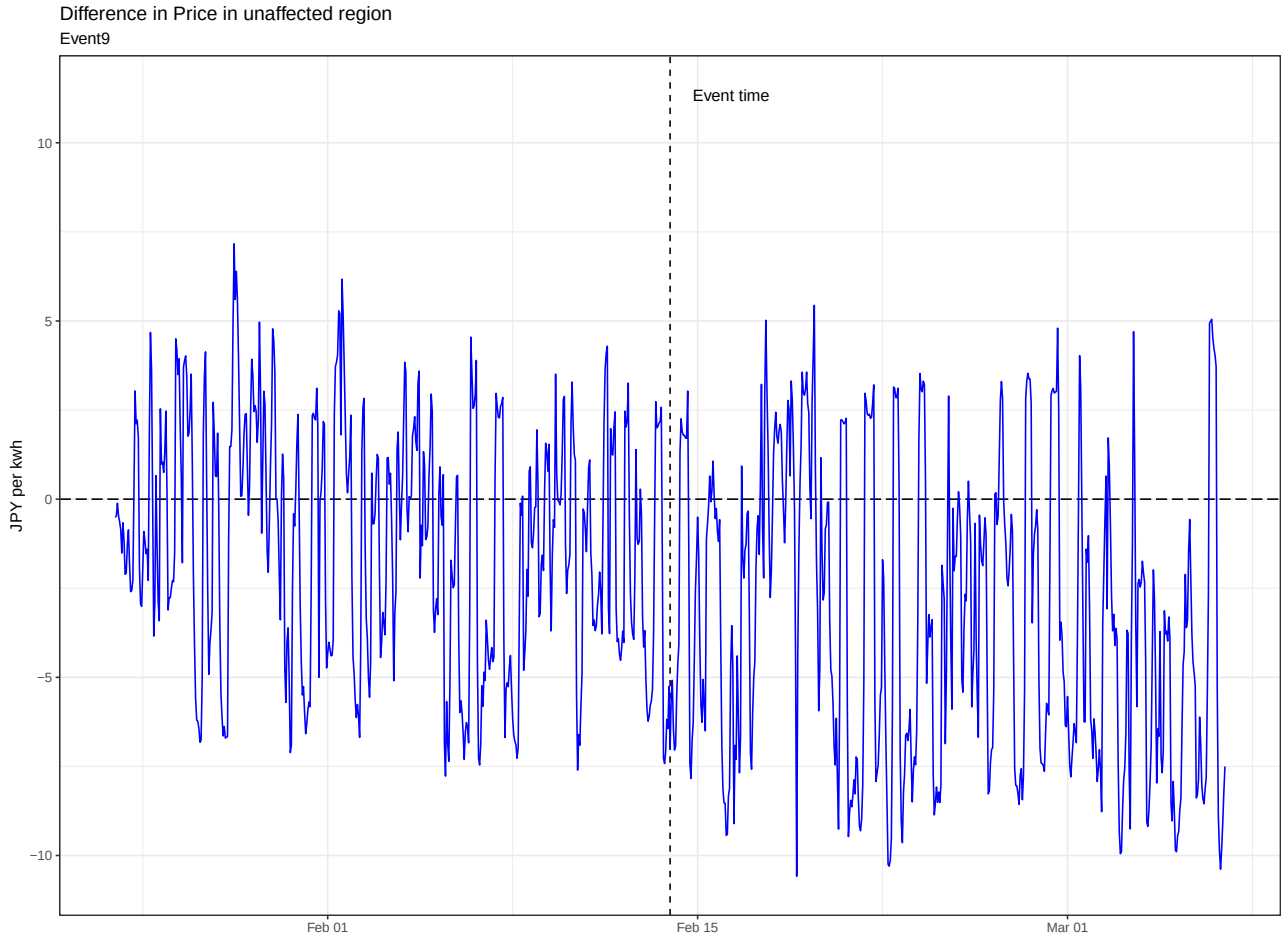
Affected region in this earthquake event



- Δ(Ave consumer cost) = Δp = "actual" - "full market integration"
- Integration would have softened shocks to consumer cost in the affected region

2) ΔConsumer cost = "actual - "full market integration"

Other regions in this earthquake event



- Δ(Ave consumer cost) = Δp = "actual" - "full market integration"
- Integration would slightly increase shocks to consumer cost in other regions

Conclusion

Any feedback would be appreciated

- Today's analysis is very preliminary. Any feedback would be appreciated

- Are there related studies that can be helpful?
  - Cicala (2022) and Gonzales, Ito, and Reguant (forthcoming)—very much related, but the focus is not shocks
  - Davis and Hausman (2016) on a nuclear plant closure
  - Carvalho et al. (2021) on supply-chain disruptions from earthquake
  - Albrizio et al. (2023) on a supply shock by Russia & natural gas market integration