Spatial Analysis of the Merit-Order Effect of Wind Penetration in New Zealand

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ENERGY CENTRE SUMMER SCHOOL in ENERGY ECONOMICS

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Agenda

1. Introduction (background and motivation)
2. Data and Variables
3. Econometric Models
4. Results
5. Conclusion and Implications

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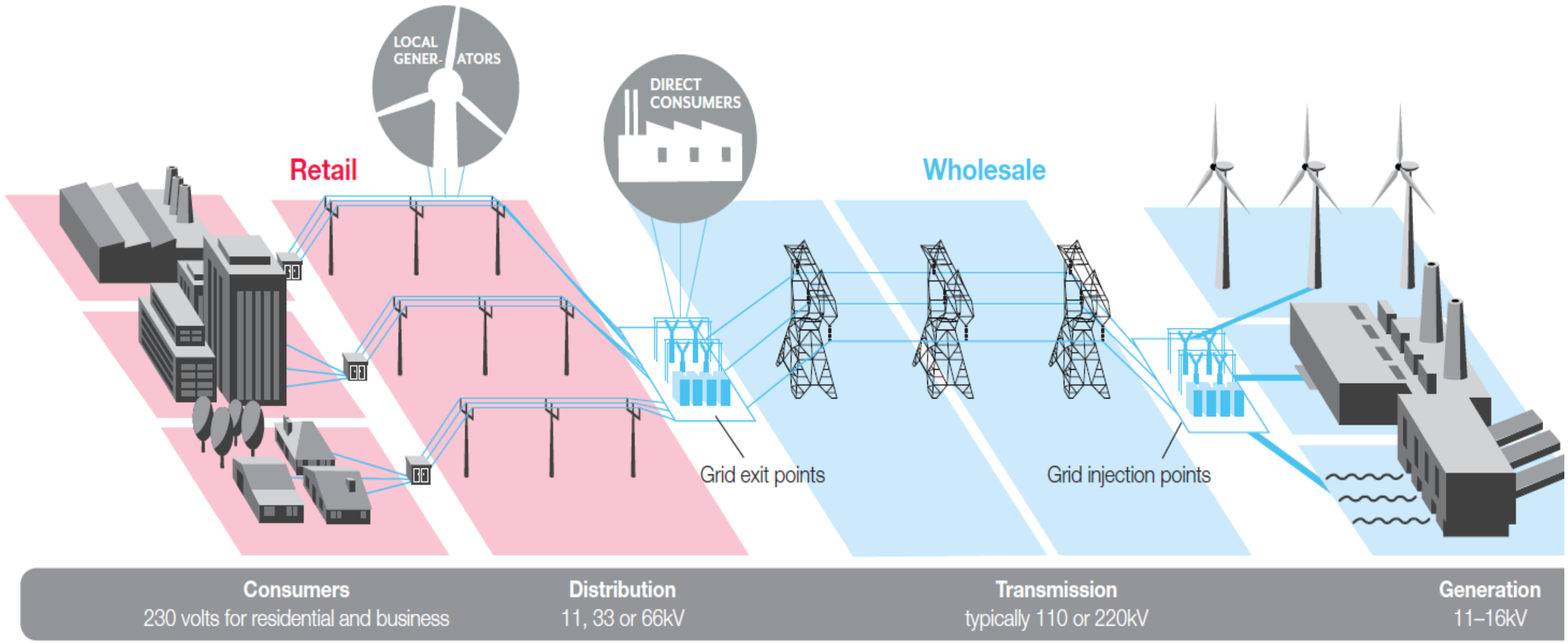
Background and Motivation

Introduction – New Zealand Electricity Market

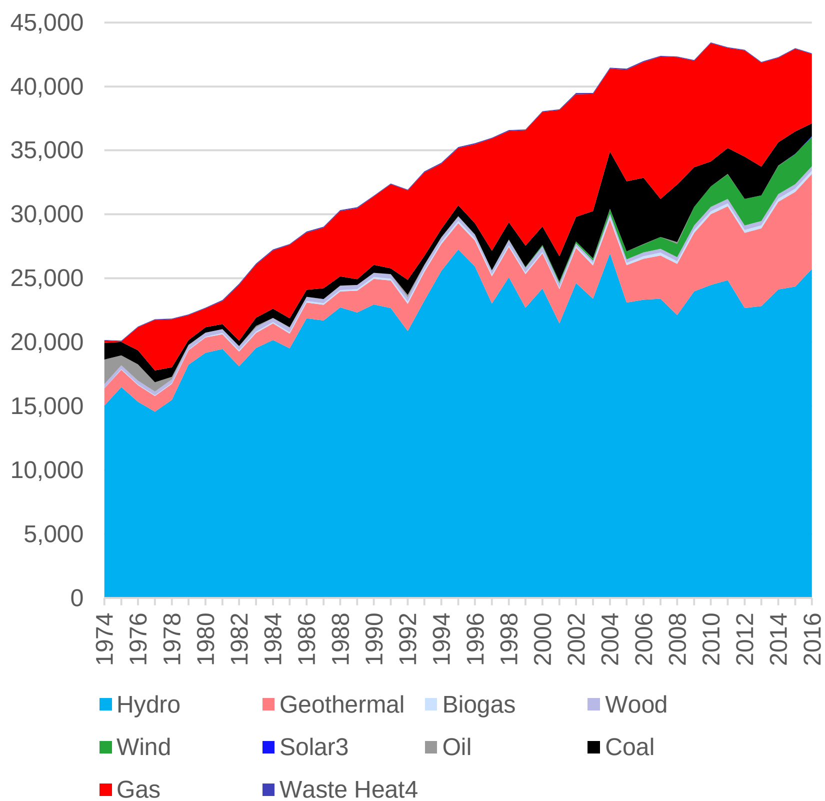


With no subsidies for the promotion of renewable resources, New Zealand's deregulated market provides an ideal opportunity for the examination of the MOE of wind.

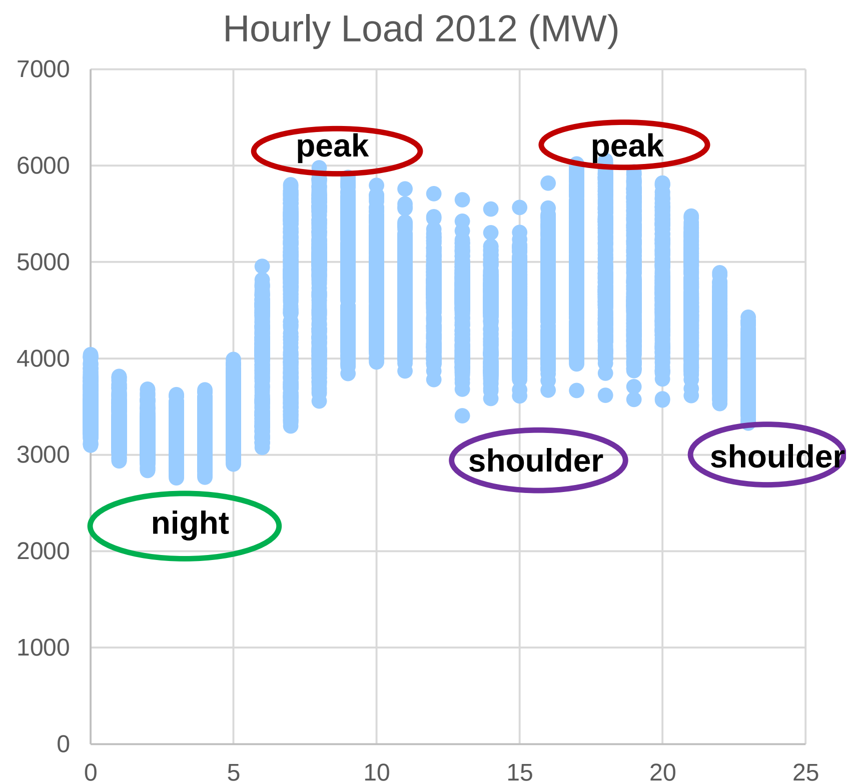
Background and Motivation

Introduction – NZ Electricity Supply and Demand

Annual Electricity Generation By technology 1974-2016



Hourly Electricity Demand



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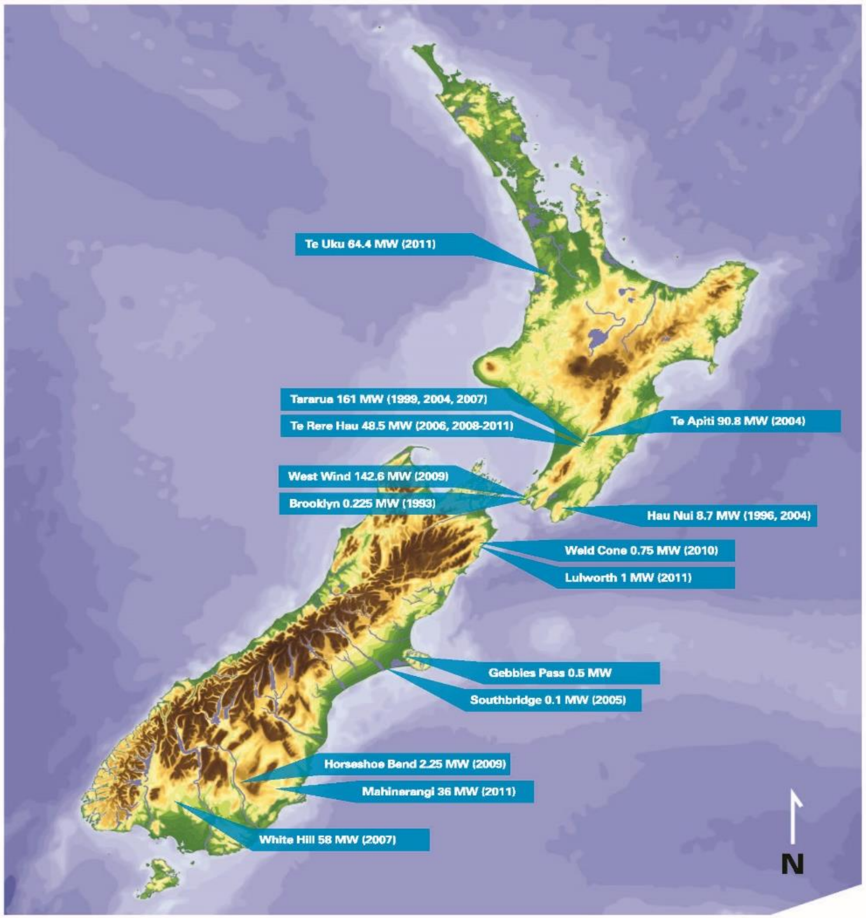
Source: Ministry of Business, Innovation & Employment, Energy in New Zealand (2017); New Zealand Electricity Authority's Centralised Dataset (CDS) 2012

Background and Motivation

Introduction - Background

NZ Wind Farms	NZ Wind Generation



- 19 wind farms;
- Good wind resource with a capacity factor around 40%;
- Wind contributes 5-6% of electricity;
- 90% of electricity generated from renewable resources by 2025;
- Limited hydro expansion;
- Consented for a further 2,500 MW;
- Wind could contribute 20% by 2030.

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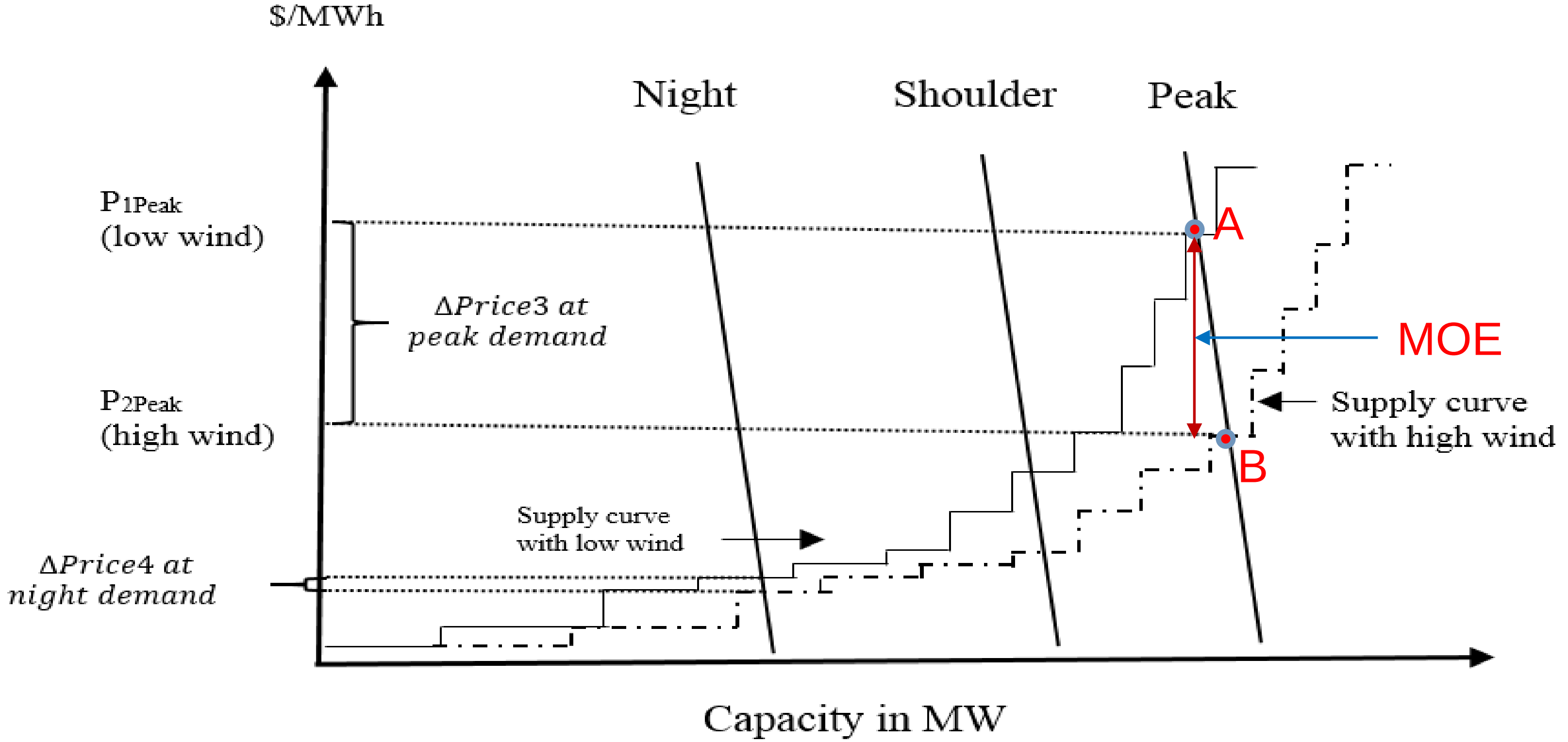
Background and Motivation

Introduction – MOE of Wind

Merit-order effect of wind power in different demand



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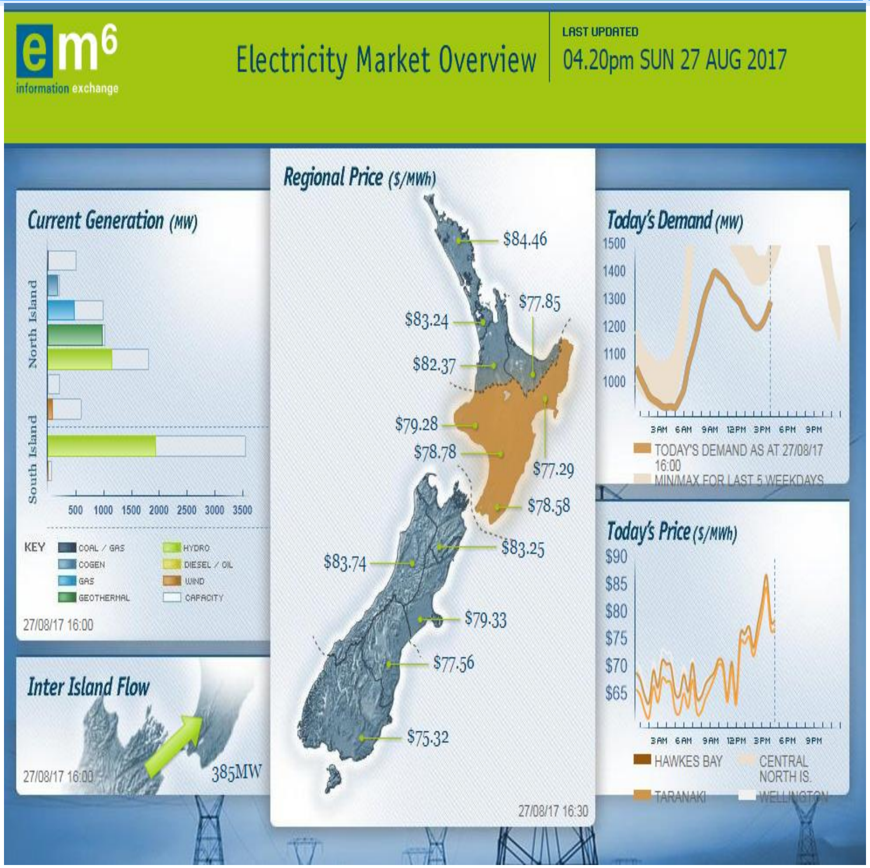
Background and Motivation

Introduction - Motivation

Geographical Diversification



Source: Energy Market Services (EMS), http://www.em6.co.nz/em6/faces/pages/login.jspx

Neighbourhood effects

- The NZEM is characterized by nodal connections and geographic spread.
- Inspired by the first law of geography: "everything is related to everything else, but near things are more related than distant things" (Tobler, 1970).
- **Hypothesis:** The nodal price is influenced, not only by factors at the grid injection point, but also by factors at the neighbouring nodes.
- A spatial model is employed to study the issue of local geographic spill-overs between nodal price and wind penetration.

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Data & Variables

- Data
  - *New Zealand Electricity Authority's Centralised Dataset (CDS) 2012*
- Explanatory variables
  - *wind/load, hydro/load, thermal/load, load, weekday, spring, summer, autumn*
- Dependent variable
  - *Nodal price($/MWh)*

Econometric Models

- Model 1: Non-Spatial Models

- $Y = X\beta + \varepsilon,\ \varepsilon \sim N\ (0, \delta^2 I_n)$

- *Ordinary Least Square (without correction for endogeneity)*

- *Panel Fixed Effects (without considering spill-over effects)*

- *Price =* $F_{1\_OLS/FE}$ *(wind/load, hydro/load, thermal/load, load, weekday, spring, summer, autumn)*

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Econometric Models

Modelling Space

- Model 2: Spatial Models

  - Row-standardised spatial weight matrix W

$$W = \begin{pmatrix} 0 & w_{12} & w_{13} & w_{14} & w_{15} & w_{16} \\ w_{21} & 0 & w_{23} & w_{24} & w_{25} & w_{26} \\ w_{31} & w_{32} & 0 & w_{34} & w_{35} & w_{36} \\ w_{41} & w_{42} & w_{43} & 0 & w_{45} & w_{46} \\ w_{51} & w_{52} & w_{53} & w_{54} & 0 & w_{56} \\ w_{61} & w_{62} & w_{63} & w_{64} & w_{65} & 0 \end{pmatrix}$$

  - Elements of the row-standardized spatial weights matrix W:

$$w_{ij} = \frac{\frac{1}{d_{ij}}}{\sum_{j=1}^{6} \frac{1}{d_{ij}}} \quad (i,j = 1, \dots 6; i \neq j)$$

d_{ij} is the distance between nodes i and j.

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Spatial Models

Generalized Spatial Durbin Model (SDM)

$$y_{it} = \alpha + \rho \sum_{j=1}^{n} w_{ij}\, y_{jt} + \sum_{k=1}^{K} X_{itk}\, \beta_k + \sum_{k=1}^{K} \sum_{j=1}^{n} w_{ij}\, X_{jtk}\, \theta_k + \psi load_{it} + \phi \sum_{j=1}^{n} w_{ij}\, load_{jt}$$

$$+ \sum_{i=1}^{3} M_i\, season_{it} + \pi weekday_{it} + \mu_i + \gamma_t + v_{it}$$

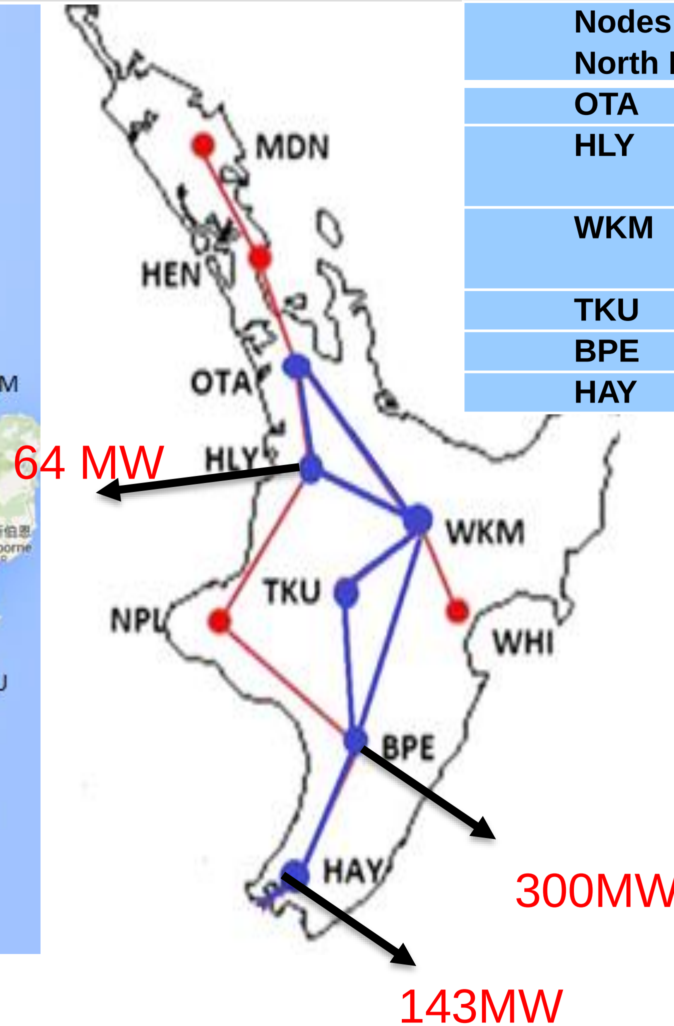
The spatial lag of y

An average of the generation mix from neighbouring nodes

An average of load from neighbouring nodes

Econometric Models

Spatial Models for the North Island



Nodes in the North Island	Plant types
OTA	Thermal
HLY	Thermal, Wind
WKM	Geothermal, Hydro
TKU	Hydro
BPE	Wind
HAY	Wind

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Results

Result 1

The Spatial Fixed Effects of Wind Penetration on Nodal Price 2012 (North Island by Demand Segments)

Coefficients (standard errors)

	Peak			Shoulder			Night		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
wind/load	-5.111***	-26.10***	**-31.21*** **	-3.897***	-19.69***	**-23.59*** **	-2.946***	-14.13***	**-17.08*** **
	(0.671)	(3.242)	**(3.908)**	(0.327)	(1.524)	**(1.845)**	(0.195)	(0.945)	**(1.139)**
Other variables	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations		17,568			17,568			17,568	

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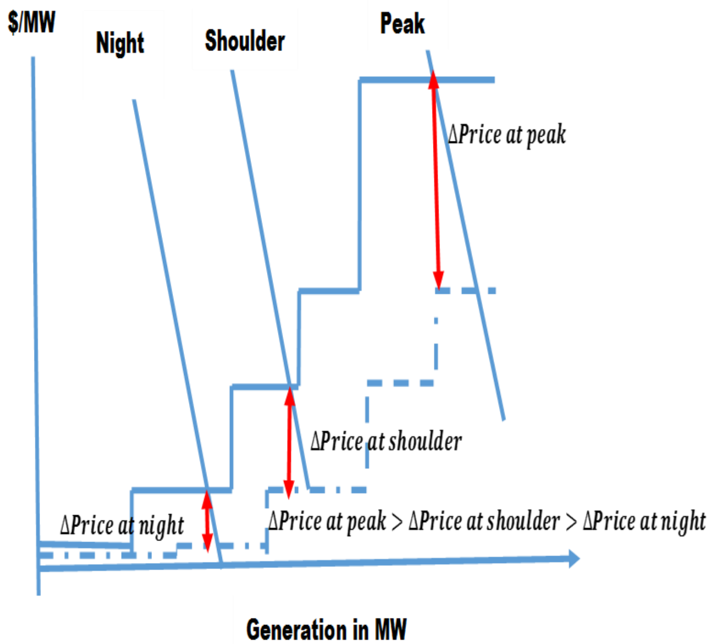
Results

Result 2

The Spatial Fixed Effects of Wind Penetration on Nodal Price 2012 (North Island by Season and Demand Segments)

Coefficients (standard errors)

VARIABLES	peak	shoulder	night
		spring	
Wind/load	-26.51*	-15.91***	-14.01***
	(15.85)	(3.693)	(1.833)
		summer	
Wind/load	-36.41***	-33.68***	-21.43***
	(3.897)	(3.536)	(2.548)
		autumn	
Wind/load	-43.03***	-38.68***	-12.74***
	(5.434)	(3.293)	(2.448)
Other variables	YES	YES	YES



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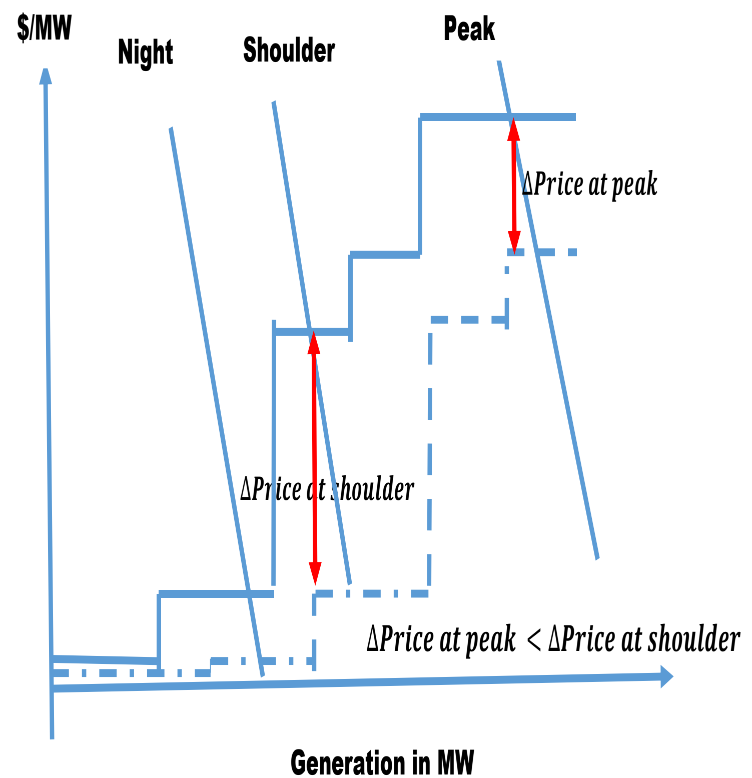
Results

Result 2 *(continued)*

The Spatial Fixed Effects of Wind Penetration on Nodal Price 2012 (North Island by Season and Demand Segments)

Coefficients (standard errors)

	winter		
VARIABLES	peak	shoulder	Night
Wind/load	-14.05*	-19.94***	-11.69***
	(7.884)	(5.973)	(2.706)
Other variables	YES	YES	YES
Observations	4,416		



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Conclusion and Implications

Conclusion

- Increased amount of wind injected into the grid lowers nodal price.

- A negative and significant relationship is found between nodal prices and wind penetration, both directly and indirectly.

- Ignoring spatial spill-overs leads to an underestimation of the impact of wind generation on nodal prices.

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Conclusion and Implications

Conclusion *(continued)*

- Surplus wind generated electricity can be exported to neighbourhood nodes, which reduces nodal price at those sites.

- The significantly negative spill-over effects indicate that scalability would be a big advantage in a small electricity system like NZ where investment in additional turbines will occur as demand increases.

Conclusion and Implications

Implications

- The ability of spatial regression models to provide quantitative estimates of spill-over magnitudes and to allow statistical testing for the significance of these represents a valuable contribution of spatial regression models to the understanding electricity prices.

- The entry of load balancing investments into the market will depend on the relative cost of alternative technologies.

- The magnitude of MOE depends on the relative difference in marginal cost of generation technology.

Conclusion and Implications

Implications *(continued)*

- This study provides the system operator and investors with valuable information when increased wind penetration leads to a need to consider flexibility, and the cost of fuel switching in time of day and dry or wet seasons.

- This methodology is applicable to analysing the cross-border effects in any electricity system that has export or import opportunities from neighbouring countries such as Switzerland or Germany.

Thank you for your attention!

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