Electricity price hedging and fat tails in renewables-rich grids

Farhad Billimoria[1], Rahmat Poudineh[2]

[1] Corresponding author: farhad.billimoria@wolfson.ox.ac.uk. Dept. of Engineering Science, University of Oxford and Visiting Research Fellow, Oxford Institute for Energy Studies, Oxford, UK
[2] *Senior Research Fellow & Director of Research, Electricity Programme,* Oxford Institute for Energy Studies, Woodstock Road, Oxford, UK

A challenge persistent in scarcity-based market designs for electricity over many years has been the absence of markets for long-term contracts to hedge away volatile price exposures between generators and consumers. These *missing markets* (Newberry, 2016) have been attributed to a range of factors including retailer creditworthiness, market structure and the lack of demand side interest from consumers (Mays et al 2022, Batlle et al 2023). Using a stochastic equilibrium model and insights from insurance theory, we demonstrate the inherent challenges of hedging a legacy thermal portfolio that is dominated by volatile fat-tailed commodities with significant tail dependence. Under such conditions the price required for generators to provide such hedges can be multiples of the expected value of prices. In the context of the transition, we show how increasing penetrations of resources like wind, solar and storage can add tail-diversity and improve contractability.

Fat-tails, tail dependence and aggregation

To provide a new perspective on this issue we draw from other risk hedging markets, and most specifically insurance (Billimoria et al 2022). A central principle of risk management is aggregation. Firms hold not one contract, but a portfolio of contracts, diversified across location, customer type and time. Holding such bundles offers diversification benefits and stabilizes losses, and allows insurers to offer afforable insurance contracts to consumers.

However, there are three factors in electricity markets that challenge traditional risk-management techniques when it comes to supporting long-term contracts.

- Fat tails are a statistical concept used to describe the distributions where the tails decline very slowly. Fat tails are particularly problematic in risk markets due the higher than normal likelihood of events at the very ends of the distribution, but also the higher than normal likelihood of events within a standard deviation of the mean. A range of studies in electricity markets around the world suggest the presence of fat-tails in electricity markets (Boothe and Glassman, 2003; Huisman et al 2022), as confirmed by extreme value theory (EVT) analysis of NEM prices.
- Tail dependence relates to the tendence of random variables to co-occur in the extremes. That is the random variables will be concentrated in the tails. The failure to consider tail dependence can result in a significant underestimate of loss exposure. EVT analysis of the Australian markets suggests strong tail dependence across thermal fuels.
- Finally, the aggregation of risks across location and time tends to amplify risk exposure. A common source of aggregation in contestable retail markets is the timeliness of electricity bills typically on a monthly or quarterly basis.

Risk Hedging in Electricity Markets

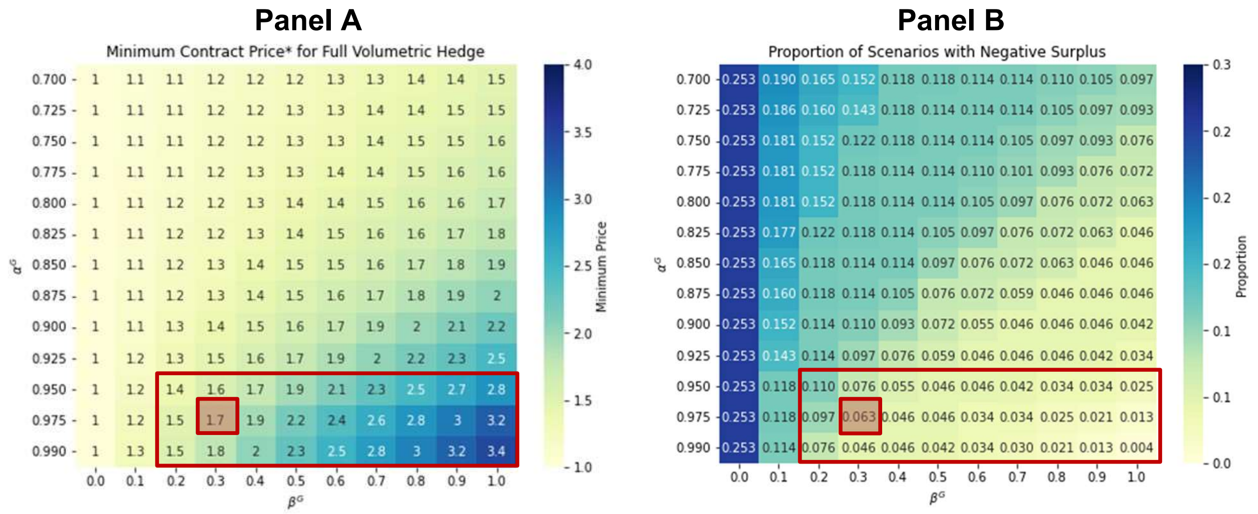
Using a risk-averse stochastic equilibrium model, we model spot and long-term risk hedging markets and a range of different risk attitudes and supply mixes in the NEM. Four resources cases are considered based on ISP trajectories:

- Case 1 – thermal dominated mix (25GW coal, 16 GW gas and liquids, 4GW renewables)
- Case 2 – low-VRE
- Case 3 – mid-VRE
- Case 4 – high-VRE (3GW coal, 29GW gas and liquids, 62GW renewables, 6GW storage)

Using the Thermal Dominated case as an illustration, Figure 1, Panel A shows a density plot (heatmap) of the minimum contract price required under different risk parameters – risk aversion β and tail risk thresholds α. The price is shown as a multiple of the expected (risk-neutral) value of spot prices. Panel B shows the proportion of scenarios where the generator has a negative cashflow surplus (i.e. cashflow loss). Higher proportions are indicative of higher counterparty solvency risk.

It is observed that at low levels of risk aversion and low tail risk thresholds (relatively low values of β^G and α^G respectively), a gentailer would be willing to execute contracts at, or close to the expected value of spot prices. However, for such risk parameters the gentailer experience negative surplus in a higher proportion of scenarios (for example, ~26% in the risk neutral case). The key implication for the deliverability of contracts relates to potential counterparty credit or solvency risk given revenue insufficiency in higher portions of scenarios. At higher levels of risk aversion and risk comprehension, solvency risk improves (with negative surplus in a much lower percent of scenarios (<2-3%). However, the required contract prices for the gentailer to deliver full volume contracts also increases, reaching ~2-3 *times* multiples of the expected value of hedge cashflows.

Figure 1. Heatmaps for Minimum Contract Price for Full Volumetric Hedge (Panel A) and Proportion of Scenarios with Negative Surplus, for Case 1 – Thermal Dominated



* Contract Price specified on a relative basis as a proportion of expected (risk-neutral) hedge cashflows.

The results suggest that there is an implicit tradeoff between contract deliverability and price – however it is the scale of such change in the context of tail risk that is relevant. It also provides an underlying rationale for the traditional illiquidity and lack of depth in long-term risk hedges between suppliers and consumers. In short, the implicit risk of deliverable hedge contracts in a thermal-fuelled grid requires prices well in excess of what budget-constrained consumers may be willing to accept. As a result, much risk remains uninsured over the long term, resulting in affordability crisis during sustained scarcity events and price shocks (e.g. the global energy crisis of 2022).

Using a set of "deliverable contract" parameters with a risk aversion level of 0.3 and a tail risk threshold of 0.975 we examine risk-hedging outcomes under differing resource mixes in Table 1. As the level of VRE penetration increases, the model records declining minimum contract prices, and lower negative surplus proportions. Contracting appetite for consumers also increases with a steep gradient towards full contracting as proportion of VRE and storage in the supply mix increases.

Table 1 Risk hedging outcomes for differing resource mix under deliverable risk-hedging contract

Resource mix case	Min. Contract Price ($/MWh)	Neg. Surplus proportion	Consumer contract appetite
Case 1 – thermal dominated	1.71	6.3%	0.00
Case 2 – low VRE (28%)	1.59	5.1%	0.92
Case 3 – mid VRE (61%)	1.38	4.2%	0.98
Case 4 – high VRE (79%)	1.34	4.2%	0.99

The shifts in contract pricing can be attributable to the improved diversity of exposure at the tail of the probability distribution. The addition of wind, solar and storage reduces the concentration of fat-tailed fuel-exposed commodities and the consequent impact of tail dpenendence upon hedge pricing. This reduces the hedge price required by gentailers to support investment, and enhances the attractiveness of volumetric hedges to the consumer. However, at very high levels of VRE, the benefits of such diversity start to disspate with a new form of concentration – that is towards weather dominated resources. As such, while this may indicate improved prospects for hedgeability of contacts over term, risk focus needs to shift towards assessment of common-modes between the availability and resource potential of VRE and storage resources. System security and common-modes arising an inverter-dominated grid also requires close attention.

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