ACHIEVING RESOURCE ADEQUACY: CONTRACT FORM AND RISK TRADING WITH HETEROGENEOUS DEMAND

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Overview

The rise of variable renewable energy and storage in energy systems has called into question whether current electricity market designs are sufficient for a decarbonized future. While energy-only markets with locational marginal prices can theoretically provide cost recovery for the socially optimal mix of resources in the long-run, many systems today have turned to some form of centrally administered resource adequacy mechanism. In a future with high shares of zero-marginal cost resources, the positive skewness of revenue is expected to increase, i.e., capital costs will be recovered from fewer scarcity hours. This poses challenges for risk management, especially with incomplete markets in risk, exacerbating concerns about the ability of short-run markets to achieve resource adequacy.

Furthermore, demand will play an important role in a future low-carbon power system. Rapid and sizeable growth in energy demand is expected over the coming years due to the electrification of transport, buildings, and industry as well as the expansion of data centers, due in large part to energy demand for generative artificial intelligence. Distributed energy resources (DER) enable greater flexibility, self-supply, and market participation as price-responsive demand.

However, energy consumers are heterogeneous – differentiated by demand profiles, flexibility, reliability requirements, and risk appetite. While passive consumers may seek flat rates and always-on service, active industrial and residential consumers as well as data centers may have flexible and deferrable demand and differentiated value-of-lost-load. Of relevance is the endogeneity of energy consumption, e.g. data center investment that is contingent upon the price, volatility and contractability of energy supply.

Market design and risk will directly impact such outcomes, including the willingness and capability of differing consumers to enter into risk-trading contracts of different forms and structures. This work provides an analytical framework to compare different contract forms in a risk-aware environment.

Methods

We formulate a mixed complementarity problem for incomplete markets and solve via a non-algorithmic approach that allows for exploration of multiple equilibria. We use this model to explore worst-case equilibria for reliability, allowing for a comparison of the consumer welfare from a resource adequacy perspective under different contacting regime, levels of demand elasticity, and demand growth.

Computational challenges typically make the problem of finding exact market equilibria under incomplete markets in risk intractable. Prior work typically uses algorithmic methods, e.g., decomposition algorithms [1] to find an approximate market equilibrium; however, algorithmic methods cannot provide assurances about the nature of equilibria that were not found. It is possible that multiple market equilibria exist with differing outcomes in terms of e.g., consumer welfare, emissions, non-served energy, etc. We build off a new primal-dual method developed in [2] that makes trivial assumptions about the relationship of the uncertainty distribution to the parameters chosen in the conditional value at risk (CVaR) formulation to significantly reduce the binary variables in the problem.

While authors in [2] explore multiple equilibria under incomplete markets with fixed demand and no risk trading, we extend this method to the consumer problem by including price-responsive demand, endogenous demand growth, and risk trading between consumers and producers. Risk trading is represented by a suite of contracts including base and peak swaps, simple load-weighted swaps, standard call options, and average rate call options

Recent proposals for organized long-term markets can be explored by simulating the mandatory forward contracting proposed by [3-4] as swap contracts and idealized capacity markets as standard call options.

Results

Preliminary results demonstrate that it is possible to solve a tractable primal-dual problem with contracting on the same scale as that in [2] without contracting. Early results show a variety of equilibria can be found with contracting, justifying the development of the non-algorithmic approach that allows for the exploration of multiple equilibria.

Conclusions

The primary contributions of this work are (1) formulation of a non-algorithmic method for incomplete markets with risk-trading (2) incorporation of a multitude of swap and option contract designs (3) incorporation of endogenous demand in market participation and risk trading. From this framework, we can explore which contracts designs are appropriate for which types of heterogeneous demand. These conclusions should in turn influence the ongoing debate on organized long-run markets for electricity. Extensions to this work can easily consider other combinations of available contract forms with energy price caps, centralized procurement, and strategic reserves.

References

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