# Optimal Arbitrage with Limit Orders in Day-Ahead Electricity Markets

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## Overview

In electricity markets, arbitrage trading may often present opportunistic profits to participant and improve system stabilisation [1][2]. Ultimately it increases market efficiency by reducing mispricing. Against this background, research on inter-market trading has become active, e.g. between day-ahead and intraday markets [3], day-ahead, intraday and balancing markets [4], auction and continuous markets in intraday market [5], intraday markets and balancing markets/imbalance prices [1][2]. However, while these previous studies consider which markets to trade and when, they rarely consider the more nuanced decision of at what price to bid or offer. This is perhaps mainly because of the focus upon the day-ahead auctions with uniform market clearing prices for successful bids and offers, as in [3][4]. We refer to this as an example of a market order focus. Thus in considering possible arbitrage between the day ahead and intraday or real time price, having forecast a difference between the two prices, a market order would bid or offer sufficiently high or low to ensure success in the day ahead auction at the market clearing price. In contrast, it is an open question how the arbitrage profits may differ if optimal limit orders on the bids and offers were to be placed. These would set offers and bids above and below which they would execute trades. Furthermore, it is useful to analyse how the relative value of each trading strategy varies from market to market. This study provides an empirical analysis using real data from (immature) Japanese and (mature) GB electricity markets and shows that optimal arbitrage from limit orders can on average increase arbitrage profits more than market order strategies. Moreover, the relative improvement is larger in the GB electricity market, where inter-market price differences are relatively smaller.

## Methods

Here we define arbitrage between the day-ahead price (DAP) and the imbalance price (IBP). First, in a strategy with 'market orders,' the forecasted values of DAP and IBP (or IBP minus DAP) are obtained prior to the day-ahead market trading, and if DAP is estimated to be higher/lower than IBP, an offer/ bid is made to sell/buy in the day-ahead market, and this position obtained at DAP is then settled next day at IBP. In contrast, using the same forecasting method, the optimal price for simultaneous limit orders can be derived. This is the price at which arbitrageurs make simultaneous offers and bids to be executed by the auction if the market clearing price is above or below, and the executed positions ultimately reversed and closed at the IBP. For both market and limit order price forecasts we used regression equations, estimated in a daily rolling manner.

## Results

Simulated backtests were carried out for three cases: arbitrage between DAP and IBP in the Japanese market, and arbitrage between DAP and IBP or MIP (Market Index Price, related to the intraday market price) in the GB market. In all cases, arbitrage profits were significantly higher for the limit order strategy compared to the market order strategy, and the improvement was much larger in the GB electricity. These profits can be further improved by using weather forecasts as well as demand and renewable energy forecast information.

## Conclusions

Whereas the arbitrage profit from market orders can be interpreted as compensation for eliminating inter-market price differences, the 'additional' arbitrage profit from limit orders may be interpreted as compensation for reducing the uncertainty in the DAP. The proposed method can be applied not only to financial players, but also to the trading strategies of solar and wind energy producers. From a market monitoring perspective, these results provide a new perspective on market efficiency tests using arbitrage considerations.

## References

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