**A PARTIAL-EQUILIBRIUM MODEL OF THE ELECTRICITY MARKET**

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## Overview

We present a microeconomic model of the electricity market which has a simple connection to the rest of the economy, due to a quasi-linear utility function. There are two parameters that shift electricity demand between points of time, one additive and one multiplicative. The correlation between these shifts and the supply from Variable Renewable Electricity (VRE) sources is crucial for the equilibrium price of electricity. Based on these equilibria we compute the value factors of VREs, as well as producer and consumer surpluses. An emerging outcome of the model analysis is that value factors of VREs decrease (within limits) as their penetration gets higher, which is also commonly found empirically.

## Methods

This paper analyses the effects of the compostion of the power supply on performance of the electricity market. We start from the frequent observation that Variable Renewable Electricity (VRE) sources, like wind turbines and solar panels, are notoriously uncontrollable and unpredictable, due to variations in wind speed and solar radiation. While the VREs have low environmental impacts, the intermittence is likely detrimental to their economic value. This is essentially determined by the electricity prices that prevail at times when the VREs are supplying power in large quantities. If, for example, the supply of VREs is high when demand is moderate, the price will be low and thus the social value of VRE will be limited.

We formulate a simple microeconomic model, with the electricity market at its centre and with a quasi-linear utility function. The electricity market is thus connected to the rest of the economy only through the income that is left over for other goods, and the marginal utility thereof. We use the model to numerically analyze the equilibria of the electricity market at different points of time, with a special focus on the variability of supply from VREs. The equilibria are then used to examine the welfare effects of different scenarios, including the value factor of VRE.

Since electricity can be considered as a time-heterogeneous good, the focus of our paper is on the variability of supply and demand between different points of time. On the supply side, this variability stems from the VREs, as discussed above. However, it may be stabilized by the introduction of large batteries for power storing. On the demand side, a central issue is how flexible consumers are when it comes to reallocating their use of electricity to times when supply is high, for instance by washing clothes and dishes during night. In the widely cited paper by Joskow and Tirole (2007) intertemporal transfers in demand is not allowed: demand at any time depends only on the price faced by the consumer at that time. In this paper we attempt to get around this limitation by use of time-varying subsistence levels of electricity consumption to get some `time-flexibility' in demand.

The model is used to analyze the hourly equilibria of a large number of years numerically, by computations of the welfare effects of different scenarios, including the value factors of VRE at different degrees of penetration. The equilibrium analysis is conveniently focused on the various degrees of correlation between two quantities, namely the electricity supply from intermittent sources and the subsistence level of electricity use.

## Results

We find that the social value of VRE indeed depends on the correlation between the variable elements of supply and demand that were mentioned above. However, although the value factor of VRE declines when the penetration of variable renewable electricity increases, it does so only within limits. This result differs somewhat from the existing literature, where the relation usually seems to be monotone. This finding suggests that the broader concepts of indirect utility and producer surplus are more appropriate than value factors when evaluating VREs. Our results confirm that consumers benefit from a higher VRE penetration, while traditional power producer suffer.

## Conclusions

Our analysis demonstrates the importance of carefully computing the equilibrium (out of many possibilities) for each hour. This is the natural starting point for a welfare analysis with a focus on the electricity market. It also provides a possibility to analyse the profitability of traditional power generators in the face of an increasing share of renewable power sources.

We consider this model as a useful starting point for several interesting extensions. First, it can be applied to the question of integration between separate power systems. What are the costs and benefits of building new and costly transmission lines? Second, it is straightforward to integrate pollution effects from non-renewable generators and analyze the optimal level of penetration in the light of welfare effects of positive environmental effects from VREs.

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