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Economics Letters 88 (2005) 121–125

**economics
letters**

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The nature of supply side effects on electricity prices: The impact of water temperature

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Received 8 October 2003; accepted 20 December 2004

Available online 20 April 2005

Abstract

In this paper, we show that the impact of water temperatures on electricity prices observed in Europe in summer 2003 has prevailed for years. We trace its source to technological and regulatory constraints and draw lessons for modelling.

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Keywords: Electricity; Deregulation; Supply factors

JEL classification: Q41; G14

1. Introduction

Electricity prices in Europe reached record heights in summer 2003. The recent deregulation of the energy sector allowed market prices to reflect supply or demand imbalances, providing economists with useful data.

Deregulation has replaced vertically integrated monopolies by competitive markets worldwide. In the Netherlands, deregulation proceeded at a brisk pace after the enactment of the European directive 96/92. All consumers became free to choose their suppliers in 2004 and large industrial users and some

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residential consumers were already free to do so before. Because the transmission of electricity is considered a natural monopoly, it remains under the control of a state-owned company (TenneT). Day-ahead futures contracts on electricity are traded on the Amsterdam Power Exchange (APX). There, buyers and sellers agree to exchange a fixed amount of electricity for the next day in hourly time blocks. Each day, TenneT receives bids from all generators and matches them to the actual demand for each hour of the day resulting in an hourly ‘APX’ price. Prices are posted on the Internet, guaranteeing a wide dissemination of the information. More complex derivatives are traded on the over-the-counter market.

2. Characteristics of electricity prices

The literature on electricity derivatives typically uses financial models developed earlier for pricing options on stocks and fixed-income securities like diffusion, jump-diffusion and regime-switching models. A review of the models can be found in [Pilopovic \(1998\)](#) and in [Eydeland and Wolyniec \(2003\)](#). However, electricity is not a typical asset: it must be produced and cannot be stored easily. This makes it unwise to blindly apply these traditional models to electricity prices. The customary inclusion of well-documented time regularities of electricity prices (seasons of the year, days of the week, hours of the day effects) is not sufficient; one has to take into account the physical constraints affecting the production of electricity. Because consumption of electricity is generally smoother than production, short-term spikes are more likely related to supply shifts than demand shifts. Consequently, we restrict our attention to supply factors.

Despite the differences in ownership and market structures across the world, there are striking similarities between the characteristics of electricity prices ([Del Buono, 2000](#)). Electricity is difficult to store on a small scale and impossible on an industrial scale. The lack of inventories leads to highly volatile spot prices compared to other commodities. Price spikes are often caused by production failures or weather-related events. Regulations can also have an impact on electricity prices insofar as they constrain production. Still, market tensions tend to subside: the price of electricity is a mean-reverting process.

Although electricity is a unique commodity, lessons can be drawn from research on other commodities with high storage cost, like frozen concentrated orange juice (FCOJ). As [Roll \(1984\)](#) and [Boudoukh et al. \(2003\)](#) show, FCOJ prices on futures markets are significantly affected by weather conditions in the producing regions. Boudoukh et al. also show that the relation between temperatures and FCOJ prices is non-linear because the effect of weather on the supply of oranges is non-linear. The key factor is temperature but only if it is close to or below freezing. A similar non-linearity, albeit with a different threshold, is also fundamental in electricity prices.

3. Technological and regulatory constraints

Power plants require constant cooling to function. The traditional cooling method is to take in water from rivers and release it at higher temperatures. Environmental regulations, like the Clean Water Act in the United States, set limits on the temperature of discharged water and the temperature increase. In the Netherlands, the temperature of discharged water must be below 30 °C and the increase in water temperature from the cooling process must remain below 7 °C.

To secure the continuity of electricity supply in the Netherlands and the integrity of the network, public and private partners in the energy sector have created a national monitoring system of the level of available excess production capacity. When the need arises, TenneT issues public warnings according to the level of power reserves at TenneT's disposal and the speed at which the capacity can be brought into the grid. The warnings are color-coded: green (no problem), amber and red (crisis).

Power plants appear to be set up so that the average difference between the temperatures of the water in and out is about 7 °C. Consequently, 23 °C is the “alert threshold” for the water temperatures. Indeed, the monitoring system described above goes into effect if this threshold is reached at Lobith, located on the Rhine near the Dutch–German border. Regulators can temporarily ease restrictions on outlet water temperatures so as to increase production. If the situation remains precarious, TenneT can decide to stop the export of electricity and opt for preventive, controlled interruptions of service.

4. Summer of 2003

The summer of 2003 was one of the hottest in European history. The historic heat records of 1947 and 1976 were broken in many parts of the Continent. The duration of the heat wave contributed to increasing water temperatures all over Europe and reduced the flow of water in rivers. High air temperatures and consequently an increased use of air conditioning pushed the demand for electricity up, while high water temperatures and low water levels put significant constraints on electricity supply. The effect was skyrocketing electricity prices with the threat of rolling blackouts.

Table 1 shows average APX prices during the most critical time. The high average price in week 33 was mainly due to the price spikes on Monday 11th, Tuesday 12th and Wednesday 13th of August. For the first time since its creation, the APX raised the maximum bidding price from 1600 to 1800 euros/MW h and then to 2000 euros.

Many countries preferred to allow temporary increases in exhaust-water temperature ceiling rather than to face cuts in service. This was especially the case for countries relying on nuclear power like France, where it accounts for about 80% of electricity production, and Germany, because nuclear power plants are slow to start and costly to stop.

5. Historical perspective

The record-breaking heat of the 2003 summer rendered evident the relation between water temperatures and electricity prices. However, past data suggest that this relation also holds for less

Table 1
Average electricity prices around the Code-Red week (10–15 August 2003)

Prices in Euro/MWh	Week 32 (08/04–08/10)	Week 33 (08/11–08/17)	Week 34 (08/18–08/24)	2003 (01/01–08/03)
Base	46	255	32	36
Peak	60	373	40	46
Off-peak	19	19	16	17

The rows show the average APX price over the whole day (base load); the period between 8h00 and 24h00 GMT (peak); and the period between 0h00 and 8h00 GMT (off-peak). Electrical power is measured in megawatts.

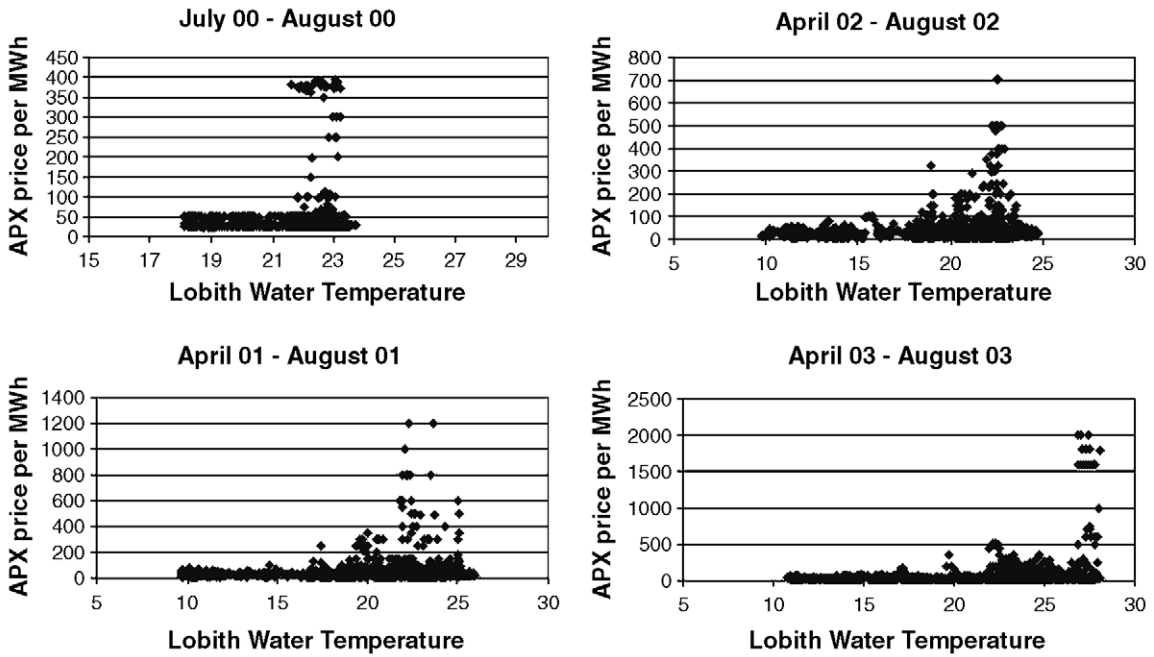


Fig. 1. APX prices and water temperatures since deregulation (July 2000). Most high prices occur at water temperatures higher than 22–23 degrees.

extreme situations. The data collected on the APX market and at Lobith since 2000 (see Fig. 1) show clearly that, when water temperatures hover above 22/23°, prices become significantly higher.

To investigate the period before deregulation, we use data collected by the regulator at the time, SEP, on production shortfalls between 1995 and 2000, when environmental regulations and technical production factors were fairly similar to today. Fig. 2 clearly shows the impact of the 23° threshold in water temperatures on the availability of production capacity.

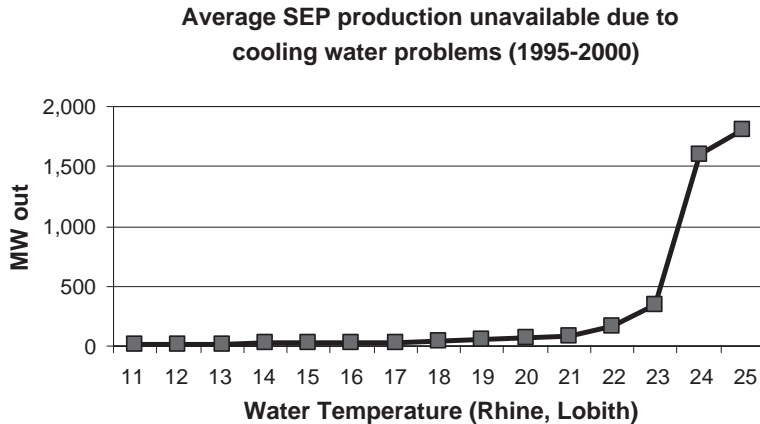


Fig. 2. Average production unavailable due to cooling water problems before deregulation.

The heatwave was a systemic shock for European electricity markets. All countries were affected by the same patterns of increasing demand and decreasing supply. Usually, a country facing supply shortfalls in electric power can rely on temporary increases in imports to fill the gap. The extent of the heatwave made this strategy inoperative: during the summer France, normally, the region's largest exporter dramatically cut exports. As a consequence, the Italian regulator had to use rolling blackouts, which affected even major cities like Rome. Furthermore, hydroelectric power generation was compromised by the drought-induced water scarcity.

6. Conclusion

The events of the 2003 summer have started a debate on the energy policy in the Netherlands. Issues range from reducing the dependency on cooling water by building more cooling towers (despite the visual impact) to handling interruptions of service and fostering international cooperation regarding electricity exports in difficult times. The lesson for financial economists is that they must take into account supply factors to properly model electricity prices.

Acknowledgements

The authors thank Menke Ubbens and Alena Musilova for reading earlier versions of this paper.

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