German power price cointegration with fuel prices

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Cointegration between power and fuel prices

Cointegration has become an important concept in contemporary time series analysis, also in the financial and energy-financial world. The time-series variables X and Y are cointegrated if there exists a linear combination of the variables $a_1X + Y$ which is integrated of order 0, whereas the individual variables are not. Another formulation for this is that $Y - a_1X$ is a stationary time-series, i.e. it is reverting to a mean level a_0. The concept can be extended to more than 2 variables: the variables Y and X_1 to X_n are cointegrated if there exist parameters a_i such that $Y - \sum_{i=1}^{n} a_i\, X_i$ is stationary around a mean level of a_0.

There is a fundamental reason why power prices and fuel prices are cointegrated, which is the simple fact that most power is (still) produced from fossil fuel. More importantly, these fuel-fired plants are often the marginal producers, and hence setting the price. This mechanism is most commonly visualized with a merit order, where demand is fulfilled first of all by non-dispatchable sources, primarily solar, wind and most of nuclear. Because that is often not enough to fulfill demand, production with gradually higher marginal production costs are dispatched too. In many countries this second part is built up of efficient coal plants, less efficient coal plants or more efficient gas plants, and finally less efficient gas and oil plants (peaking stations). A merit order is not a perfect representation of reality, where start costs, must-run obligations and a range of other power plant limitations play a role as well, but are hard to capture in a simple merit order. However, it is an intuitive representation of the price setting mechanism in power markets.

Cointegration in energy price models

If power and fuel prices are cointegrated, then it is important to include this characteristic in price models which are used for valuation and risk management. Because of the fundamental reasons and because of statistical evidence, for over a decade now, KYOS has cointegration as a central element in its price models, such as the Monte Carlo simulation engine KySim. And we have regularly written about cointegration in various publications (see KYOS Knowledge Center: http://www.kyos.com/knowledge-center)

We have experienced over and over again that the inclusion of cointegration has a substantial impact on results, for example the estimated extrinsic value of a power station. Without cointegration, power prices can diverge more freely from fuel prices, so spark and dark spreads exhibit a larger variability. Cointegration keeps the variability within a narrower range and hence leads to lower extrinsic values, which are almost certainly more realistic. As a consequence, delta hedges and risk metrics (Earnings-at-Risk, Value-at-Risk) become more realistic with cointegration too.

Testing for cointegration: speed of mean-reversion

In order to test how cointegrated power is with fuel prices, we can apply standard cointegration tests. There are basically two approaches: either the relationship between power and fuel prices[1] is a priori known, i.e. the parameters a_i are known, or they are not. In the former case, we may estimate first of all how often a certain fuel is setting the market price, i.e. is marginal. For example, if we believe that gas plants with around 50% HHV efficiency are always the marginal plants in peakload, we can expect a parameter weight of 2 on natural gas prices. In addition, we can expect a weight of 2 x 0.205 = 0.41 on CO_2 (EUA) prices, assuming a carbon content of 0.205 ton/MWh for natural gas. It is important to realize that the assumed relationship must not be derived from the *average* proportion of gas and coal in the fuel mix (which may be low), but on the proportion of time it is the marginal fuel (probably much higher). Note that the example assumes that gas prices are in the same unit as the power prices. If not, they have to be transformed first to the same unit, which is also the case for coal.

If we don't want the cointegration analysis to be dependent on the marginal fuel price assumptions, the parameters a_i can be estimated with historical data. This is what happens in the Engle-Granger two-step estimation process:

- First estimate the stationary relationship, generally by ordinary least-squares

  $$Power_t = a_0 + a_1 Gas_t + a_2 Coal_t + a_3 CO2_t + \varepsilon_t$$

  Where $Power_t$, Gas_t $Coal_t$ and $CO2_t$ are the power, gas, coal and CO_2 price levels at trading date t. The prices can be spot or forward/future prices.

- Then estimate how stationary the relationship is, for example by estimating the size of the mean-reversion parameter β in the resulting time series of residuals

  $\varepsilon_t - \varepsilon_{t-1} = \beta \cdot \varepsilon_{t-1}$, where

  $$\varepsilon_t = Pow_t - (a_0 + a_1 Gas_t + a_2 Coal_t + a_3 CO2_t)$$

KYOS uses a slightly different version of this two-step approach. In the second step, instead of a regression involving the *absolute* power prices and *absolute* fuel mix, natural logarithms are taken. This has the benefit that the cointegration relationship can be part of a larger modeling framework where prices are commonly modelled in form of their natural logarithm and log returns. More precisely, we assume that the power price log returns tend to be negative when the (log) power price is above the (log) equilibrium level, and vice versa:

$$lnPow_t - lnPow_{t-1} = \gamma \cdot (ln(a_0 + a_1 Gas_{t-1} + a_2 Coal_{t-1} + a_3 CO2_{t-1}) - lnPow_{t-1})$$

If the parameter γ is larger than zero, and statistically significant, then the (log) power prices are mean-reverting to their equilibrium level. In economic terms, we test if the power prices tend to move downwards (and fuel prices upwards) when power prices are high relative to the fuel prices, and vice versa.

[1] When referring to 'fuel prices', then emission prices are also assumed to be included.

Cointegration analysis of the German power market

The German power market is not only large in absolute size, but also the most liquidly traded in the center of Europe. It has undergone a massive transformation in recent years as a result of the 'Energiewende': the move to renewable sources, away from nuclear and fossil fuels in power generation. This transition has been a mixed success: wind and solar power capacities have exploded, and nuclear is gradually phased out, but at the same time the coal-fired production has increased and the overall CO_2 emissions hardly fallen or even risen, because coal has largely pushed gas out of the production mix.

We ask ourselves the question how the whole German power market transition has impacted on the drivers of power prices, in particular the cointegration relationship between power and fuel prices. The rise renewable generation could imply that the relationship has weakened: in some hours the power prices are negative and cannot be explained by fuel prices, but at the same time nuclear production has fallen.

The analysis was performed on year-ahead forward prices, separately for peak load and off-peak, where off-peak was calculated from the baseload and peak load prices. End-of-day settlement prices for German power and NCG gas prices are from EEX, API2 coal and EUA emission prices from ICE. Compared to spot prices, the use of forward prices has the advantage that the short-term effects of weather and demand variations do not impact the analysis. Furthermore, year-ahead prices are among the most liquid forward contracts, and not affected by seasonal influences.

Because we did not want to make a priori estimates of the price setting fuel mix, the equilibrium relationship between power and fuel prices is historically estimated. This is step 1 of the Engle-Granger approach. Step 2 uses the logarithmic formulation. Parameters are re-estimated every 3 months with a 1-year rolling historical window. The same analysis has also been performed with a 2-year rolling window, with similar results.

Estimated marginal fuel mix in the German market

Figure 1 shows the coal and gas parameter estimates of the equilibrium relationship between power prices and fuel prices. The coal parameters are multiplied by a factor 5 to make them more in line with the size of the gas price parameters[2]. The regressions lead to rather similar patterns for peak (orange) and off-peak (blue) over time. It can also be observed that the coal price weights (solid lines) are quite similar, whereas the gas price weights are larger for peak than off-peak. This makes sense, because peak prices are higher especially, and often require also less efficient gas plants to produce.

[2] The multiplier of 5 can also be justified by the fact that a MT of coal contains around 7 MWh of energy, combined with the around 25% lower efficiency of a coal plant versus a gas plant: 7 x 0.75 is close to 5.

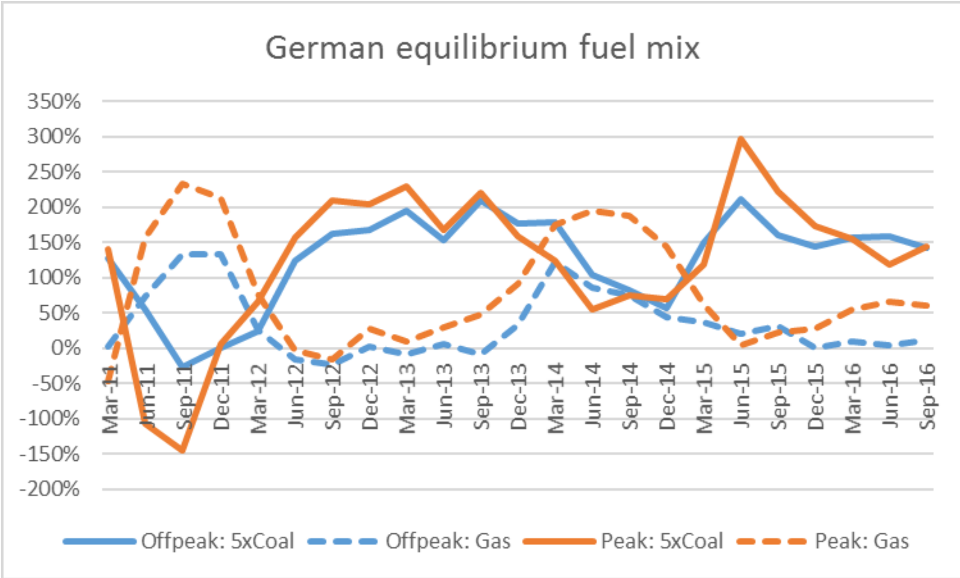

Figure 1: German estimated power price drivers: parameter estimates from a regression on year-ahead forward prices

Less understandable are the negative weights in 2011, 2012 and part of 2013. This could indicate that the power price formation was not so stable, for example because of regulatory uncertainty. This may have resulted in a rather unstable and also quite incomprehensible relationship between power and fuel forward prices.

Most interestingly is the relative weight on gas versus coal: in 2011 the gas weights are high, in 2012-2013 low, in 2014 high, and finally in 2015-2016 low. Note that the estimates are derived from year-ahead prices, and estimated with a 1-year historical window. For example, the high gas weights in 2014 may be explained by the fact that in 2013 and 2014 the market was expecting gas to be the primary marginal fuel in the year ahead. Then in 2015 and 2016, expectations shifted when the market understood that the Energiewende was pushing gas almost completely out of the fuel mix, making coal the primary price driver again.

Speed of cointegration in the German market

In the Engle-Granger estimation process, the second step reveals how strong the mean-reversion is in the estimated market spread: the power price minus the fuel price mix. Using daily price differences, this parameter γ reflects the daily speed of mean-reversion. In figure 2 the mean-reversion parameter is shown for off-peak and peak.

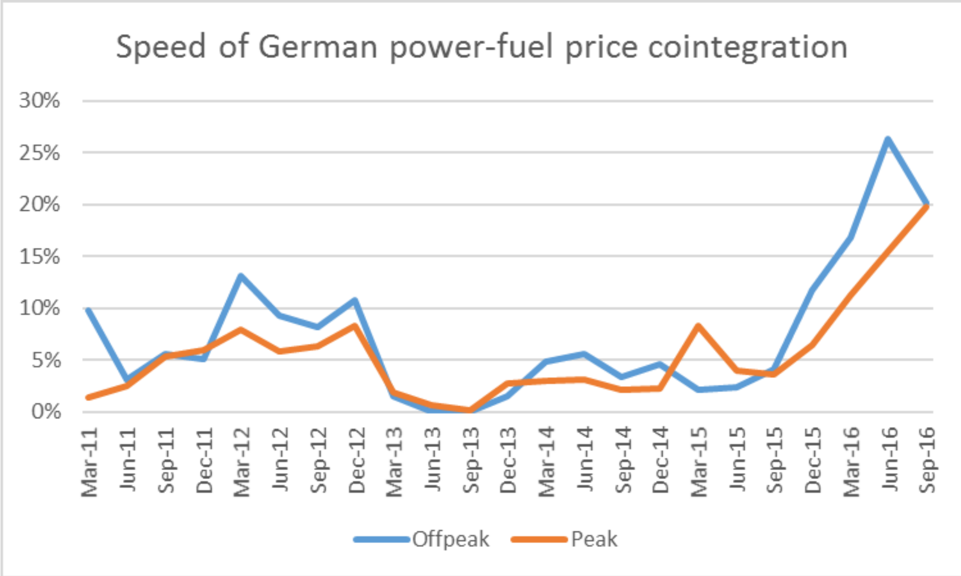

Figure 2: German power price mean-reversion to equilibrium fuel mix

Most striking is the sharp increase in mean-reversion in the last 12 months. Whereas the period from 2013 to halfway 2015 exhibited rather low levels of mean-reversion (0-5%), the most recent estimates from September 2016 are 20%. In other words, it seems that the market is quite certain how power prices should depend on coal and gas prices (year-ahead), and any deviation from this equilibrium is quickly reverted.

Figure 3 shows this pattern graphically for calendar 2017 forward prices. The peak load regression of the equilibrium fuel mix yielded parameters of 0.596 for gas, 0.289 for coal[3], 1.106 for CO_2 and 3.697 for the constant. This was estimated on 8 September 2016 with 1 year history of year-ahead forward prices. From September 2015 until September 2016 the power prices closely moved together with the estimated fuel mix.

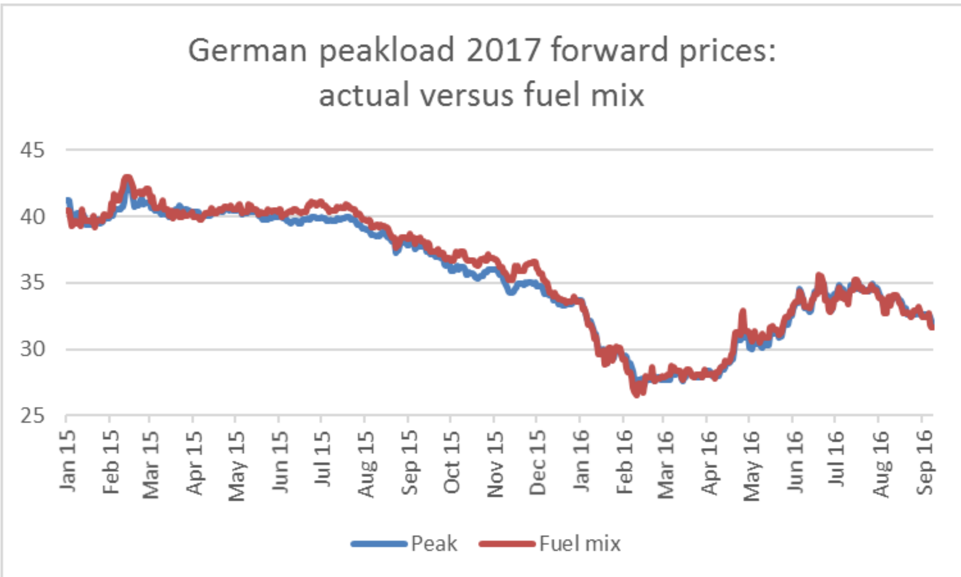

Figure 3: German 2017 calendar forward prices: actual and estimated based on fuel prices

[3] Multiplied by 5, as in graph 1, this is 1.445.

Practical application

This analysis provides a statistical analysis of the German power market. It shows how closely year-ahead fuel forward prices have moved together with power forward prices. This analysis could be performed without any assumptions about the market fundamentals. This type of analysis is very relevant for valuation and risk management, especially with a horizon of up to about two years. It captures how market prices actually move, in terms of return volatilities, return correlations and price cointegration. With the observed levels of cointegration, especially in the past 1-2 years, spark and dark spreads are considerably less volatile. If this behavior in power prices is ignored, power plants and spark/dark spread options will be overvalued.

Over longer horizons, the statistical parameter estimates must be treated more carefully; a fundamental analysis may be more appropriate for long-term investment decisions. Fundamental analysis, however, is quite dependent on the assumptions about the future market structure and fuel prices. Because we believe in the relative strengths of both approaches, statistical and fundamental, KYOS provides tools for both: a primarily statistical model with cointegration (KySim), especially for the medium term trading oriented applications, and a primarily fundamental model (KyPowerFundamentals, KyPF), especially for somewhat longer-term applications. Both models can also be used jointly: the statistical model generates Monte Carlo simulations of fuel prices, which the fundamental model uses to generate power price simulations.

Implications for the future

For the German power market, and essentially all European power markets, the primary question is how the renewables growth is going to affect prices further. Power prices have already declined sharply and the profitability of conventional generation is very poor. Will this trend of lower power prices and lower margins continue? And if so, what mechanisms will drive the power prices, and how important will be the role of coal and gas to set the prices? We believe both statistical and fundamental analysis help to provide answers. So far, even though absolute power prices have decreased, our statistical analysis shows that power prices are closely connected to fuel prices, even more so than several years ago.

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