Foundation for Research on Market Design and Energy Trading

Towards a Better Design of Electricity Transmission Rights

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Abstract

The purpose of this paper is to discuss the market-coherent valuation of different designs of transmission rights for cross-border capacities between two countries. We show that the value of transmission rights that must be exercised in the morning -the currently prevailing design of long-term transmission rights in European power markets- is significantly below the value of transmission rights that provide a payout according to the difference of the hourly prices at neighboring spot exchanges. The conclusion is based on modeling and comparing both contract designs using a real option approach that is based on a mean reverting process for the underlying regional price spreads. We conclude that Europe could benefit from adopting a certain standard market design for transmission rights and, therefore, modifications to congestion management would be sensible alongside the more widespread implementation of Market Coupling.

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1 Introduction

Transmission has become a core element of concern in liberalized markets for power and gas across the world. The ability to move power and gas between markets has proven to be the glue for improving the correlation of prices between distinct regional markets and spurs competition in retail markets based on transparent prices in regional wholesale forward markets. As a consequence, cross-border grid access has attracted high political and regulatory attention. In Europe, this issue has been addressed in the Florence (power) and Madrid (gas) processes leading to specific EU Guidelines[4].

In practice, however, the vision of a single European market with a uniform price for power and gas has to be abandoned, as the capacity to transport will most likely continuously remain a limiting factor between regions. This is because neither generation or sourcing costs in different regions will become equal nor will costs of transmission investment decrease significantly. Thus, a debate about the most viable design of transmission rights is needed.

In power markets, the concept of Market Coupling has been intensively discussed and widespread implementation can be envisaged. Despite the existence of the Congestion Management Guideline, transmission rights between markets are, however, not at all harmonized across Europe and there are also severe differences between commodities.

Conceptually, the ability to transport a good between markets does merge the supply and demand functions of those markets and will lead to uniform prices if transport capacity is abundant and has no costs. In markets for commodities, the latter assumption does not hold true as loading, transport and unloading of commodities come at a cost which is usually to a large extent distance-dependent. In power and gas, however, those circumstances are of limited importance[5]. In a meshed network, variable costs associated with moving power or gas from A to B can hardly be identified usually. As a consequence, when moving power or gas within markets and between markets, a market participant is usually not charged with volume-specific costs.

The ability to transport from A to B enshrined in a transmission right can, thus, be described as an option on the price spread between A and B with a strike price of 0 as long as the holder of the right is not obliged to transport. When prices in A and B are readily observable and liquidity in the respective wholesale markets is sufficient, such a spread option also provides a hedge against any volatility of the spread. Thus, a market participant who has bought in A (is long in trading terminology) and holds a transmission right from A to B can sell in B (goes short in trading terminology) to close his position. To do so, however, is only economic if prices in A are lower than in B. In this case, the option to transport from A to B has a positive intrinsic value that is readily observable as the positive price difference between the markets. At the same instant, the opposite direction (from B to A) will have no intrinsic value. This feature is of specific interest for technical infrastructure, which can be used in both directions such as power transmission lines.

[4] See http://ec.europa.eu/energy/gas_electricity/forum_electricity_florence_en.htm and http://ec.europa.eu/energy/gas_electricity/forum_gas_madrid_en.htm; most specific to transmission rights is the Congestion Management Guideline (EU VO Nr. 1228/2003)

[5] Grid losses in power and the need to use compressors to move gas through a pipe do also add a variable and distance-dependent cost component to these commodities. Once a connection to the grid has been made, there are, however, no fixed costs of loading and unloading.

Prices in A and B do change and as a consequence the price spread will also vary over time. The volatility of the underlying price spread drives the time value of any option written on it. The sum of intrinsic and time value, thus, determines the overall value of the option. In comparison to usual financial instruments such as company shares, however, gas and power provide an additional complexity we would like to refer to as time granularity. Products traded in those markets do specify a delivery future period (e.g. a calendar year), but cascade into smaller time frames (e.g. months, days and hours) at a later stage. So when applying option pricing, we have to carefully assess the underlying of the option defined by the details of the contract.[6]

Commonly traded options on power are, e.g., the options on a calendar year or a month, all of which have to be exercised before the beginning of the delivery period. For transmission spread options, however, it could be envisaged that the exercise of the option could be pushed theoretically even into the real-time window. Such a definition would make a transmission right suitable for real-time deliveries usually referred to as reserve markets. As an overall first conclusion from observed prices on commonly traded options, we do find that prices of products with higher time granularity (e.g. days in comparison to calendar years) are more volatile and options on those products more valuable. Given the restricted availability of easy-to-access price information, we limit the data used in our model for the power market to two specific time granularities, which are comparably easy to get hold of: The End of Day price for baseload at d-2 (i.e. 2 days before actual delivery, referred to as EoD) and the hourly prices of the spot exchanges at d-1.

The EoD price can be accessed via the exchanges and is particularly relevant for any transmission right that must be exercised at that point in time or early the next morning. In order to match the requirements of the applied option price model perfectly, the respective prices at the time the transmission spread option exercise would be required (e.g. at 8 o´clock in the morning). When back testing, we found the difference reasonably small and did opt for publicly available and easy-to-access data.

In this paper, we do take a conceptual look at the value of transmission rights and will argue based on our findings that Europe would benefit from a certain standard market design for transmission rights. In order to do so, we compare the modeled value of two types of transmission spread options based on the distinct time series for the Dutch and the German power market and, in addition, contrast those values with the prices paid for transmission rights in the historic auctions. Section 2 describes the characteristics of transmission and value drivers for transmission rights. Section 3 provides details about the model used to value the transmission rights compared in this paper. In Section 4, we describe the model estimations and values derived. Section 5 highlights the findings and adds the empirical perspective. In Section 6, we summarize the major conclusions, while Section 7 sketches some additional aspects. Finally, an appendix is provided for the detailed tables and the same analysis is performed for the German/French border.

2 Option character of transmission rights

2.1 Transmission rights

In this paper, we focus on transmission rights that are auctioned by the TSOs for a potential exercise during all hours in one month. A monthly transmission right can be interpreted as a bundle of European call options on the

[6] See, e.g., EEX for a definition of option exercise on energy options: http://www.eex.com/de/document/83391/EEX_Contract_Specifications_0026b_e.pdf.

electricity price spread with a strike price of zero. Electricity traders who purchase a transmission right are holders of the option to either exercise, i.e. to nominate the right and as such (attempt to) benefit from a positive difference of electricity prices in the direction they hold the right to, or not to exercise. TSOs as sellers of the option are obligated to enable the option exercise when a holder wishes to nominate his right at certain points of time (see the time lapse below). In order to receive one of these limited rights, traders bid the option premium they are willing to pay in transmission right auctions organized by the selling TSOs. In the following, we qualitatively describe the main drivers of a transmission right's value.

2.2 The value drivers of transmission spread options

2.2.1 Intrinsic and time value

The value of a transmission right from A to B on the expiration date T is the maximum of the electricity price difference ($p_B - p_A$) and zero, which makes up the option's payout profile (because the strike price, i.e. the price for nomination, is zero). Before maturity, this difference is referred to as the intrinsic value. If an option's intrinsic value is positive, then it is referred to as being 'in the money'; otherwise, it is 'out of the money'. An option with an intrinsic value very close to zero is referred to as 'at the money'. The holder of a European call option will only take advantage of his right on the date of maturity if the option is in the money. Otherwise, the option has zero value.

The option´s maturity can also influence its value. The longer the option is left to mature, the higher its so-called time value, i.e. the probability that the underlying value will push in the desired direction within a certain time frame. At the term's end, the time value is zero, or in other words, by the expiration date, the option's value reflects its intrinsic value. Volatility, as a measure of an underlying margin of fluctuations, has a similar effect on an option's value. The higher it is, the higher the expected profit when the underlying value develops positively for the option holder.

2.2.2 Time of exercise

The transmission right value driver we focus on in this paper is the time of exercise. The exercise of the option is done via the nomination of a transmission schedule from the holder of the transmission rights to the respective TSOs. While details differ across Europe, there are two fundamentally different ways of nomination:

In explicit auctions, where transmission rights and electricity are traded separately, option holders need to explicitly nominate their transmission options usually in advance of the main electricity price clearing (i.e. the day-ahead hourly spot auction). We use the term "PTR" (= Physical Transmission Right) throughout the paper to describe this design of transmission rights. This type of option is currently most commonly used for congested electricity interconnections across Europe.

In implicit allocations, where electricity and transmission capacity are cleared simultaneously, transmission rights would be nominated automatically if the intrinsic value of the right (i.e. the price spread) is positive. We use the term "FTR" (Financial Transmission Right) throughout the paper to describe this design of transmission rights.[7]

[7] Note that FTRs as defined here are options and as such differ substantially from the point-to-point congestion revenue rights allocated, e.g., by the New York Independent System Operator (NYISO). Even though the latter are obligations and as such their payout can be either positive or negative, they are – somehow misleadingly – also called financial transmission rights. See, for an analysis of the efficiency of NYISO FTR markets, Adamson et al. (2010) and Deng et al. (2010).

Table 1 depicts the course of events for the explicit auctions of monthly PTRs implemented at Germany's borders to the Netherlands and to France. The transmission rights for the available capacity are auctioned on a monthly basis at predetermined dates one (Dutch border) and two weeks (French border) in advance of the monthly delivery period. In order to make use of a PTR for a certain hour, its holder has to nominate his transmission right until 8:00 am on the day preceding delivery (d-1). If, for instance, a holder of a monthly PTR of 10 MW from Germany to the Netherlands wants to benefit from an (expected) higher electricity price in the Netherlands in any hour on September 16th, he has to nominate his right until 8:00 am on September 15th. Once a right is nominated, the holder is obliged to be long in Germany and short in the Netherlands.

At the time of exercise, however, the holder of the PTR transmission right has only limited price information for the respective markets, namely the EoD prices for the most commonly traded products in markets A and B (such as the day-ahead futures) as well as the historic hourly prices in both spot markets .[8] In our model, we limit the usage of that data to the hourly prices of the previous day. In practice, prices for the standard products will also be available at 8 o´clock in the morning, i.e. just before the nomination of transmission rights takes place.

The holder of the transmission right can then use this information to make a 'best guess'-exercise of his transmission right and in practice might only nominate for some hours. Given the inevitable errors in assessing the hourly prices based on this information, some of his exercise decisions will be wrong, i.e. he will sometimes transport from A to B, although the hourly prices would make the opposite direction the economically viable choice.[9]

month-ahead	day-ahead		
Middle of the month	Until 8:00 am	9:00 am	11:00 am (12:00)
Auction of monthly PTRs	Nomination of long-term PTRs	Day-ahead PTR auctions (if not reserved for Market Coupling)	Day-ahead power auctions, i.e. APX NL, EPEX F (EPEX G)

Table 1: Typical course of events in congestion management w/o market coupling.

This slippage can only be avoided if the hourly prices in both regional markets are known. As exports and imports also affect those prices, the exercise of the transmission right has to be done simultaneously with clearing the hourly spot markets. This process has gained momentum across Europe and usually is referred to as Market Coupling.

In Continental Europe, it has been introduced with Trilateral Market Coupling between France, Belgium and the Netherlands and has, in the meantime, been extended to also include Germany. Long-term transmission rights in markets with such an implicit spot clearing can be provided as FTRs that guarantee its holder the payment of the

[8] Usually, the last available price is the price for delivering power between 11 pm and 12 pm on the day before delivery. This and the 23 preceding prices have been established in an organized auction two days before actual delivery.

[9] The same information can also be used by the TSO to calculate expected load flows as the price differences determine the commercial flows.

day-ahead hourly price spread if positive. Thus, there is no risk of mistaken nominations due to a wrongly predicted hourly price spread between the markets.

Forward	day-ahead
	12:00 am
Auction of FTRs	Simultaneous day-ahead power and transmission allocation during hourly implicit market clearing

Table 2: Potential course of events for congestion management with Market Coupling.

The comparison shows that the main difference between the two transmission rights is when the decision on the option exercise is made. Any transmission right auctioned over longer terms could as well be defined as FTR as long as there is the opportunity for automated (implicit) option exercise such as within the Market Coupling process.

2.2.3 (Financial) Firmness

Option theory calls for an undisputed right of the option holder to receive the underlying at the defined strike price. However, transmission assets may fail, making the actual physical transport and, therefore, delivery of the option underlying impossible. Most transmission rights issued across Europe, therefore, have a contract clause allowing the TSO´s to deviate even from the nominated schedule or as a preventive action to accept only partial nominations, e.g., a holder of a 10 MW may only be allowed to nominate up to 5 MW.

In that circumstance, the holder of the transmission right has to rebalance his portfolios in both regional markets, which most likely will be at unfavorable terms (so he has to sell in the cheaper market and buy in the more expensive one). Depending on time of curtailment (day-ahead, intraday or real-time), he is actually exposed to the respective spread risk. Without defined financial compensation, one could actually say that his position is completely open because while he has bought a transmission spread option, he has sold exactly the same option when allowing the TSO to curtail. In practice, actual curtailment has been hardly used by TSO´s, making the position somewhat more attractive as the potential (stochastic) exercise of the option implied by the ability to curtail has a low probability. The issue of firmness, however, is another reason why we do not expect market participants to pay the full theoretical value for a transmission spread option.

An easy measure for TSOs to avoid curtailment is to issue as little as possible transmission rights in advance. Making transmission capacity scarce also has the attractive effect (from a TSO´s perspective) such that the prices achieved for the remaining rights issued can be expected to be higher[10]. This is even more the case if TSOs would compensate at full market spread at the time of curtailment. We believe more research is required to strike the right balance between issuing transmission rights and the risk of having to compensate in case of non-performance for TSOs.[11]

[10] As the TSO is a monopolistic player for transmission, one could expect Cournot-type of behavior in defining the amount of available transmission. Enforced compensation, however, does add complexity to the simple Cournot Model.

[11] See, for the impact of different transmission right allocation methods, Vukasovic, Apostolovic (2009).

3 The valuation model

In the following, we present a model framework for the evaluation of transmission rights. Literature on price spread modeling and spread option pricing can be widely found. Most authors try to model the two underlying prices separately. Poitras (1998) derives an approximate solution for two price paths in the Black-Scholes (1973) world, and Carmona and Durrleman (2003) expand these approximations to simple Gaussian mean reversion processes. However, it can be shown that these approximations may produce unsatisfying results, since the difference between two random log-normal distribution variables cannot be approximated particularly well-based on one normally distributed random variable.

In many cases, it is even possible to quote closed-form solutions for so-called exchange options, i.e. spread options with a strike price of zero. Margrabe (1978) derive a simple closed-form solution using two correlated geometric Brownian motions, while Hikspoors and Jaimungal (2007) derive closed-form solutions for the Lucia-Schwartz (2002) model and for a two-factor model with jumps. The authors calibrate their models based on oil prices with short-term delivery. Although relatively complex and time-consuming, the calibration routine actually delivers satisfactory results for oil prices, which are less volatile than electricity spot prices.

Because of the above-mentioned disadvantages and complicated necessary calibrations, Benth and Saltyte Benth (2006) decide to model spark spreads (the difference between electricity and gas prices) directly. They derive a closed-form solution for spread options with a positive strike price, but also admit the drawback that in fact the aggregated information regarding price relationships is included in model parameters, but can no longer be separated for individual interpretation. The model proposed in this article draws on Benth's and Saltyte Benth's approach, but is geared at modeling regional price differences.

In fact, transmission rights can be seen as (a bundle of) European call options, directly written on a regional price spread[12]. Details on the contracts and on their pricing can be found in Wobben et al. (2010) and the references therein as well as in Branger et al. (2010).

3.1 The underlying model

Generally speaking, electricity prices and, thus, electricity price spreads depend on two components: a deterministic and a stochastic one. The deterministic (time variable) component *f(t)* includes all predictable structural factors in determining the price spread such as seasonal influences. The stochastic component is modeled as a sum of Ornstein-Uhlenbeck processes, which fulfill certain stochastic differential equations (SDE) and keep prices reverting around the seasonal component (see Benth (2008)). In Wobben et. al (2010), several ways of evaluating so-called financial transmission rights (FTR) are quantitatively compared and analyzed. Here, we do not concentrate on a model comparison, but analyze the price differences between financial and physical transmission rights as described above.
Therefore, the underlying price P_t represents the spread between two regional electricity prices. We describe P_t with a jump – diffusion – spike (JDS) model:

[12] Besides the approach that models price spreads directly, it is also possible to model the two regional spot prices separately. When using the second approach, the correlation of all stochastic processes included in the model must be estimated according to historical data. These estimations determine the options price to a great extent, but they can be flawed due to insufficient data or the inability to observe and separate jump components.

(1) $P_t = f(t) + X_t + Y_t$

(2) $dX_t = -\kappa X_t\, dt + \sigma\, dW_t$

(3) $dYt = -\beta Y_t\, dt + J_u\, dN_u - J_d\, dN_d,$

where W is a Wiener process and where N_u and N_d are two homogeneous Poisson processes with constant intensities h_u and h_d, respectively. J_u and J_d denote the jump sizes, while the respective densities are denoted by g_u and g_d.

Both X and Y are (non-Gaussian) Ornstein – Uhlenbeck processes that exhibit mean reversion towards zero. The use of two processes instead of one jump-diffusion process allows for a different speed of mean reversion for the two components. We assume that diffusive shocks in X vanish over a longer time period, whereas jumps in Y vanish much faster. The latter, thus, capture spikes, i.e., extreme but short deviations from the long-run level, which are separated into positive (*u*) and negative (*d*) jumps.

For the evaluation of transmission rights under this model, we assume that the change of measure exclusively influences the mean reversion level *f.* Then, the differences in the regional Futures prices can be explained by the (time-dependent) market price of diffusion risk λ_t, i.e. $f^Q(t) = f^P(t) - \lambda_t\sigma/\kappa$ (see Lucia/Schwartz (2002)).[13] The expected price spread, i.e. a Forward written on the spot price spread, is then given by:

(4) $F_T(t) = E^Q(t)[P_T|P(t)] = f(T) + e^{-\kappa (T-t)}X_t - \int_t^T e^{-\kappa (T-t)}\lambda_s\, ds + e^{-\beta (T-t)}Y_t + (\mu_u h_u - \mu_d h_d)(1- e^{-\beta (T-t)})/\beta,$

where μ_u and μ_d denote the expected down and up jump sizes. In line with intuition, a very high mean reversion speed for the spike component Y implies that current spikes, i.e. very high values of Y, have a small impact on the forward price. For the pricing of European-style options, we use Monte Carlo simulations of the spot (Equations (**1**-3) and the forward dynamics.[14]

A major objective of this paper is to analyze the influence of different times of exercise on the value of a transmission right, i.e. the difference in option values between PTRs (defined here as transmission rights with an explicit nomination requirement in advance of day-ahead price clearing) and FTRs (defined here with automatic nomination at the time of implicit market clearing).

Because monthly transmission rights on every border can be allocated in the form of either PTRs or FTRs, we need to model one of the allocation processes to enable a comparison. Therefore, we concentrate on borders where transmission rights are allocated explicitly and long-term rights are PTRs and, for a comparison, apply a model that computes option values for the virtual case where the considered markets are cleared implicitly and long-term transmission rights are FTRs. As these FTR values are modeled values that might be distorted due to model simplifications such as the assumption of firmness of exercise, we also derive modeled PTR values to enable a viable comparison of PTR and FTR values. When modeling PTRs, however, we ignore the actual ability of the holder of the option to only partially exercise, i.e., nominate only few hours of a day, but assume that the spreads are positive for all hours of the respective day if the day-ahead prices suggest that the option is in the money. Thus, differences in modeled and actual PTR auction results might provide insights on potential improvement possibilities for the actual applied PTR design as well as any value of partial exercise.

[13] Q is a so-called valuation measure, which ensures market-coherent derivative prices. The physical measure P describes historical spot prices with simulated model prices as accurate as possible (see Branger et.al (2010)).

[14] In Wobben et al. (2010) closed-form solutions for plain vanilla options are derived under some simplifying assumptions, whereas in Branger et al. (2010) closed-form solutions for options on Futures are derived.

3.2 FTR valuation

Financial transmission rights (FTR) as described here could be seen as the potential standard instrument to hedge the regional price risk in markets with Market Coupling and, thus, implicit transmission allocation. In order to model FTR values, we apply the valuation model for a bundle of European call options, directly written on the spot price spread.

(5) $FTR^{[T1;T2]}(t) = \sum_T C^T(t) = \sum_T E^Q[max(S_T - K, 0) | S(t)]$

These transmission rights are option contracts written on the spread of hourly spot prices in the neighboring markets. This resembles basically the value of transmission in a Market Coupling process with implicit allocation of transmission capacity.

3.3 PTR valuation

Unlike FTRs, PTRs are options on the expected price spreads, because nomination takes place well ahead of day-ahead market clearing (see Table 1), i.e. there is still a risk of transferring power into the low-price region. Exercising the transmission option implies the obligation to nominate a physical transport. Thus, such a PTR is an option on forward price differences. The valuation of PTRs as option contracts written on the expected spot price spread is intensively discussed in Branger et al. (2010). We model it as follows:

(6) $PTR_{T0}^{[T1;T2]}(t) = \sum_T C_{T0}^{T}(t) = \sum_T E^Q[max(E^Q[S_T | S_{T0}] - K, 0) | S(t)]$

These transmission rights have to be exercised in the morning of d-1 (the day before actual delivery), which is equal to the currently prevailing design for longer-term rights (Calendar Years and Months) auctioned off by electricity Transmission System Operators (TSOs) in the CWE Region.

4 Model estimation and valuation

The estimation as well as the empirical and statistical analysis of our model is described in Branger et al. (2010) and Wobben et al. (2010). Here, we briefly recapture the necessary steps.

4.1 Development of price spreads

We analyze transmission rights on Germany's border with the Netherlands. If we consider the Dutch border, we observe that, on average, Dutch power prices, historically, have been significantly higher than German prices. Thus, transmission rights from the German to the Dutch electricity market have been in the money, whereas rights for the opposite direction have been out of the money. However, prices have been converging in recent years and transmission rights between Germany and the Netherlands are, these days, rather at the money.

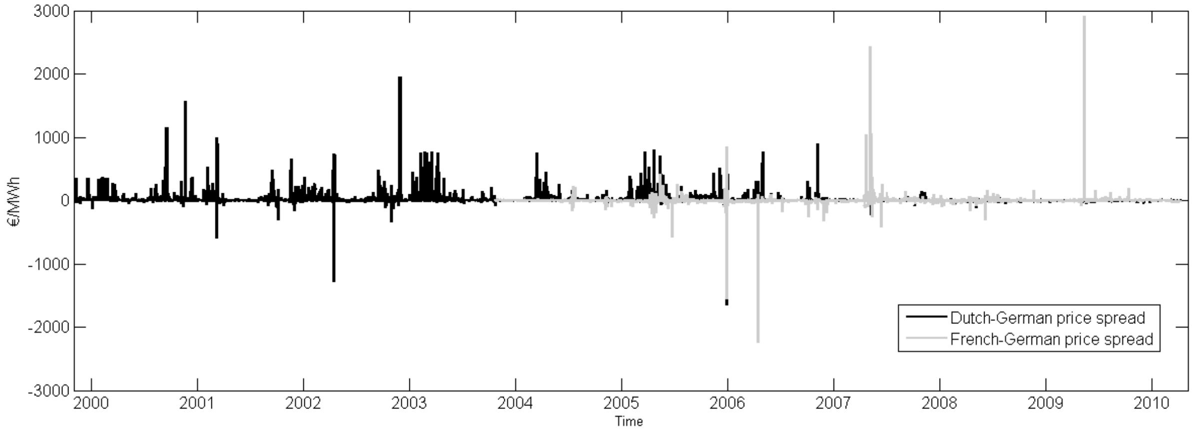

Figure 1: Hourly electricity price spreads from September 2000 (NL) and June 2004 (F) to August 2010 (without weekends).

Figure 2 depicts the moving average of the hourly spot price spread between Dutch and German prices with a lag of one year. This illustrates the decline in the Dutch German price spread from a high of 20 €/MWh in 2003 to basically the same level in 2010.

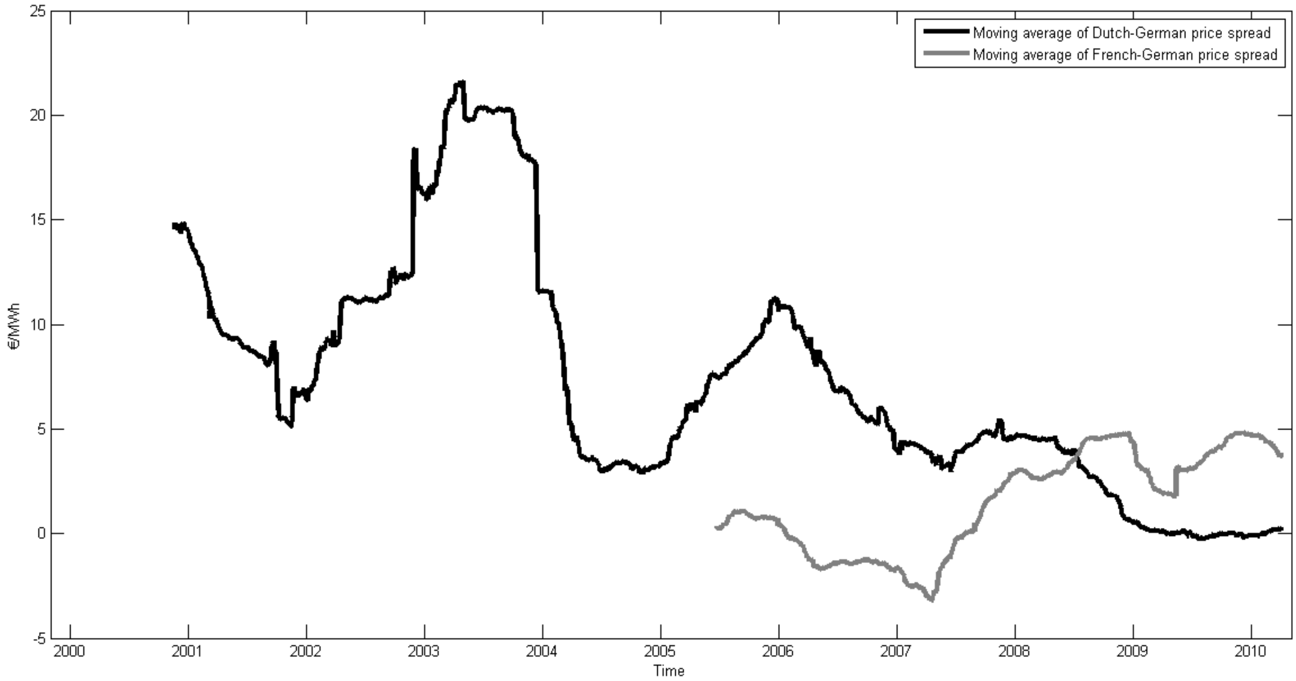

Figure 2: Moving averages (with a lag of one year) of hourly power price spreads since September 2000 (NL) and June 2004 (F).

Analogously, volatility decreased significantly during the last years, which might be assumed in a glance at the development of the hourly price spread (see Figure 1) and is reflected in the development of the standard deviation (see Figure 3).

At the German border with the French power market, where hourly power prices have been available since June 2004, the development is different. Whereas average French spot prices have been lower in 2006 and 2007, they relatively increased since 2008 and currently even exceed the German prices (see Figure 2). In contrast to the volatility of Dutch-German price spreads, the difference between German and French spot prices has become more volatile (see Figure 3).

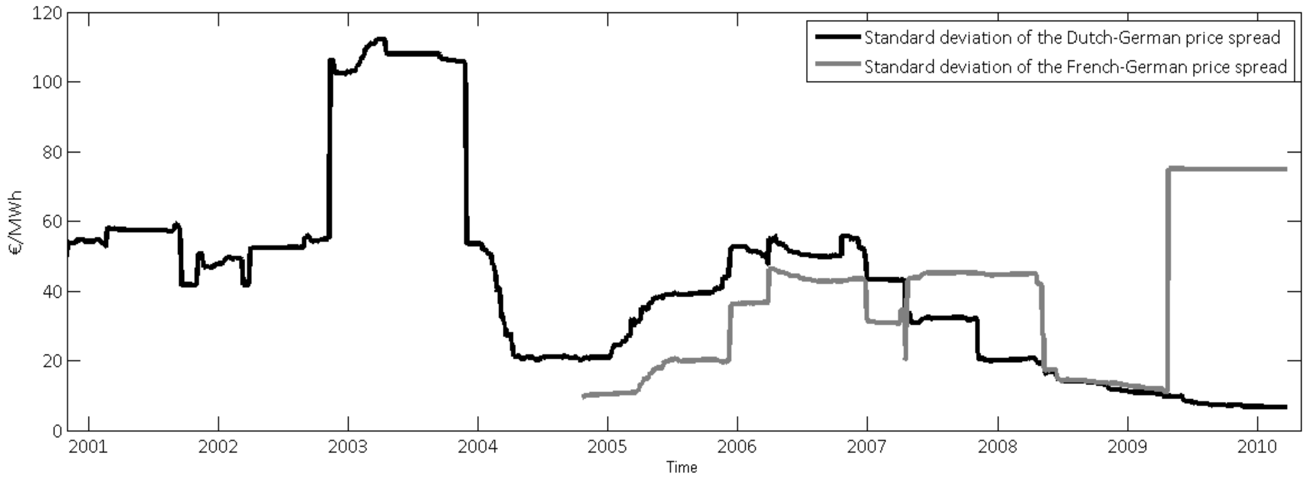

Figure 3: Standard deviations of power price spreads (hourly figures computed with the past year´s price spreads).

The figures show that regional price differences are moving and there seems already to be some trend for convergence of prices. With the introduction of Market Coupling between all three markets, the regime has changed completely, but one may assume, based on the figures available, that price convergence is even more pronounced. This moves any type of transmission spread option closer to the "at the money" point.

4.2 Data analysis and estimation

In the following, we evaluate monthly transmission rights between Germany and the Netherlands from November 2009 to October 2010. First of all, we provide some statistics of the underlying dataset (see Figure 4).

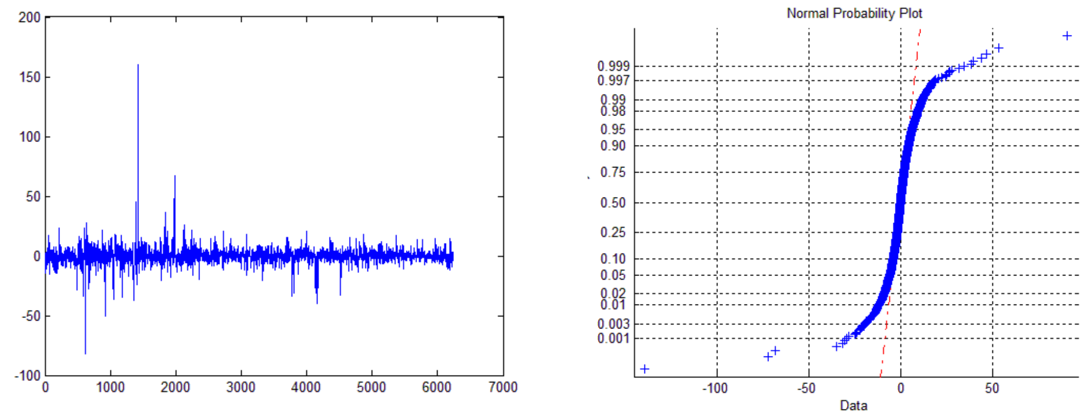

Figure 4: Original dataset - one year[15] of daily differences of the price spreads between Germany and the Netherlands (left) and the normal probability plot belonging to that dataset (right).

At first glance, our dataset seems to be heavy-tailed distributed, but nearly free of autocorrelation (except the small autocorrelation for t = 24, see Figure 5). On the one hand, that indicates that the dataset has to be filtered, such that large deviations from the mean reversion level *f* do not have any influence on the estimation of the diffusive part *X*. On the other hand, it implies that the price spread at 11 pm for the previous day is the best information for the price spread in all hours of d, i.e. an introduction of an intraday price seasonality, a time-dependent mean reversion speed or any other time dependencies within the model are not necessary.

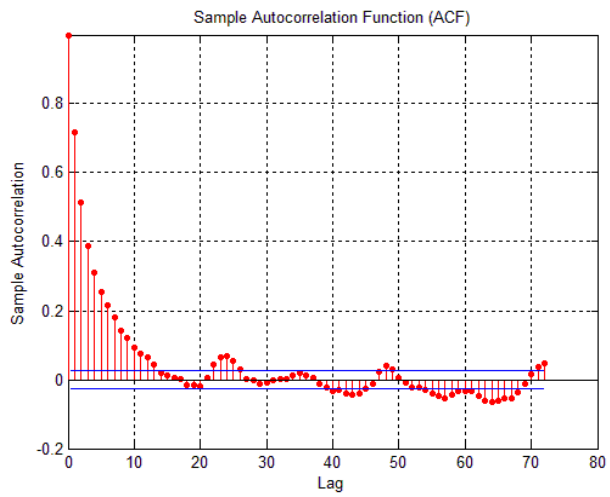

Figure 5: Empirical autocorrelation functions for the price spreads between Germany and the Netherlands.

4.3 Estimation process

The consequence we draw from the long-term development of day-ahead price spreads is that the volatility of spreads is not constant over time. In order to adequately apply a constant volatility model and capture enough

[15] Exclusively between trading days.

data, we calibrate our models for each monthly transmission right using hourly spot price differences of precisely two years ahead of the time of valuation. Thus for each valuation day, we have a new dataset, consisting of approximately 2*250*24 = 12,000 price spreads that are fitted into the model.

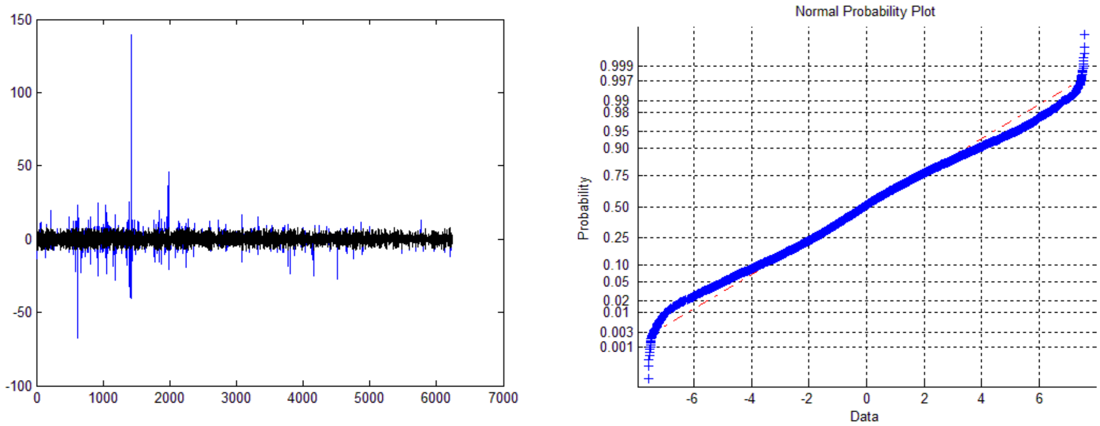

Figure 6: Filtered differences of the price spreads between Germany and the Netherlands as well as the respective normal probability plot.

Before we can estimate the processes X and Y, we apply an iterative jump filter in order to separate the dataset into diffusion and a jump part. The iterative jump filter as well as the estimation of the two processes X and Y are discussed in Branger et al. (2010) for hourly electricity prices, whereas these algorithms are applied to spread data in Wobben et al. (2010). Here, we make use of the same algorithms and similar assumptions, i.e. we assume constant jump frequencies h_u and h_d and exponential distributed jump sizes with constant expectations μ_u and μ_d.

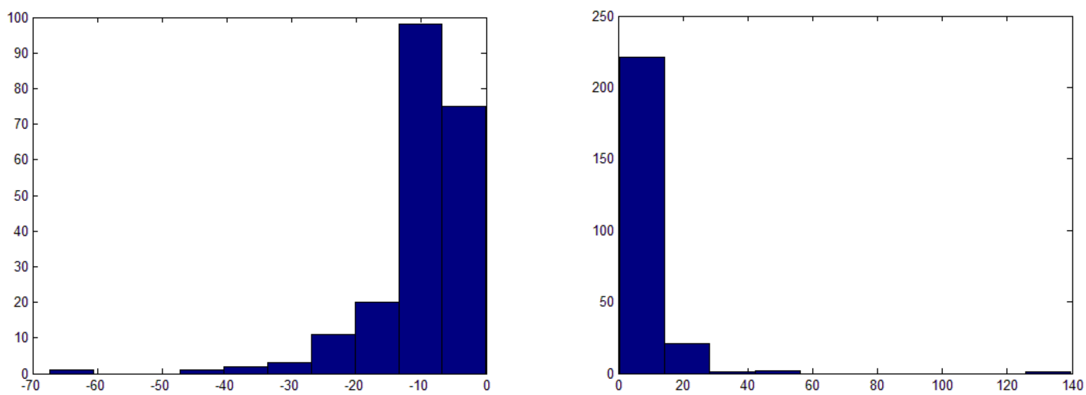

Figure 7: Histograms of the filtered negative (left) and positive (right) jumps.

First of all, we apply an iterative spike filter to the original dataset (see Table 3 for the third and fourth moments of the original dataset) in order to separate the dataset into two parts. One is describing the spikes and the other one, which is nearly normally distributed after the filtration process, is describing the diffusive part. Hence, the latter one has a skewness of nearly 0 and a kurtosis of nearly 3.

Third and fourth empirical moment of the original and the filtered dataset	Skewness	Kurtosis
Original dataset	-2.9614	144.0259
Dataset after spike filtration	0.0458	2.9687

Table 3: The third and the fourth moment of the original and the filtered dataset.

In every step all data points that deviate more than a predefined multiplier of the standard deviation of the remaining dataset are filtered out and are replaced by the mean of the preceding and the following data point. The algorithm aborts if no more spikes can be identified.

Description	Parameters (Germany - NL)
Mean reversion speed κ of X	0.2404
Volatility σ of X	3.0281
Mean reversion speed β of Y	1.0282
Mean size of negative jumps h_d	-10.1247
Frequency of negative jumps h_d	0.0338
Mean size of positive jumps h_u	9.3784
Frequency of positive jumps h_u	0.0394

Table 4: Calibrated model parameters.

In our model, jumps are activated by two independent homogenous Poisson processes, which are fully determined by their means and the reciprocal jump frequencies.[16] The jump frequency results from the quotient of the number of positive or negative jumps and the number of data points. The jump sizes are characterized by two exponential distributions, also described by their mean values, i.e. the expected sizes of negative and positive jumps. The mean reversion speed β results from a fit of the function $exp(-\beta t)$ to the empirical autocorrelation function. The remaining diffusive part of process X will be estimated via Maximum Likelihood (see Branger et al. (2010)). The results of the calibration are depicted in Table 4
Whereas the third and the fourth moments of the original dataset show that the data is far away from being normally distributed, the filtered series has a skewness close to 0 and a kurtosis close to 3, which allows dealing with it as normally distributed (see Table 3).

4.4 Monte Carlo Valuation

Having done all the necessary estimation steps, we are now able to derive the option values via the Monte Carlo method. Two underlying paths of the respective PTR and FTR model are depicted in Figure 8. Therefore, we use the Euler-Maryama discretization with a rate of $\Delta t = 0.1$ (i.e. we simulate 240 prices per day) and antithetic variables for the normally distributed random numbers as well as uncorrelated exponential distributed negative and positive Poisson-Spikes.

[16] Note that a spike is defined as a data point that substantially deviates from the mean and where the daily price difference as well as today's value itself have the same sign.

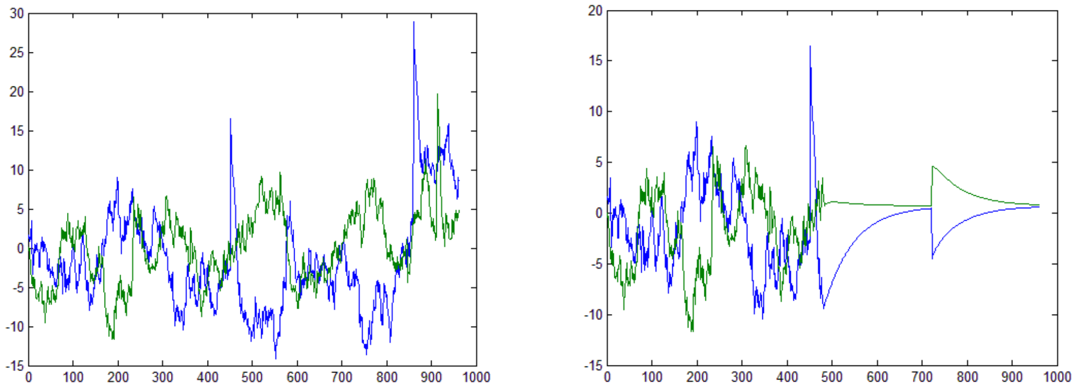

Figure 8: Simulation of hourly price spreads (left panel) and expected price spreads (right panel) for four days where expectation is taken for the last two days on the basis of the last available price of the preceding day.

We simulate m = 1, …, M with M=10,000 paths of our two models, and the respective payoffs, in order to approximate the fair value of the PTR and FTR using the arithmetic average of the simulated payoffs. Note that for the PTR model each EoD price is random, but the prices for the following 24 hours are deterministically dependent on that price, i.e. they are smoothed by the mean reversion effect and, hence, no more stochastic. Thus, in our model, either all or no hours of the following day will be nominated, since either all expected prices are in the money or none of them. We choose such a model because there is no significant autocorrelation in the data (see Figure 5).

5 Findings

5.1 Model results

With the model described above, we are able to price PTRs and FTRs for any given spread of monthly forward prices prevailing at the time when the transmission rights are auctioned. Figure 9 summarizes the results for the German/Dutch border for spreads in regional electricity price futures between -5 and +5 €/MWh[17].

The results show that PTR pretty closely resembles the intrinsic value of the transmission spread option and only has limited additional time value when the option is at the money. In contrast the FTR has significant time value in a very large interval of spreads and only comes close to the intrinsic value at spreads of -11 and +11 €/MWh when the option is deep in or deep out of the money. What is driving the difference? As modeled, the PTR will have to be nominated for all hours of the day without knowing the actual hourly spot price differences. Due to uncertainty, some hours will inevitably be nominated opposite to the optimal flow. The risk of incorrect nomination increases if the option is at the money. Thus, the time value of the PTR is mainly determined by the probability that the option is moving more into the money within the time period from pricing to exercise. In case of negative spreads, this probability is low. As a consequence, the PTR is rather worthless. In contrast, the FTR is able to fully reflect the additional value of positive spreads for single hours even if the spread of forward prices is negative. This leads to significant time value even if, overall, the option is out of the money.

[17] In the appendix we provide all computed values for the German/Dutch and German/French borders, but limit the graphical representation in this chapter to the German/Dutch border values for the diffusion process only.

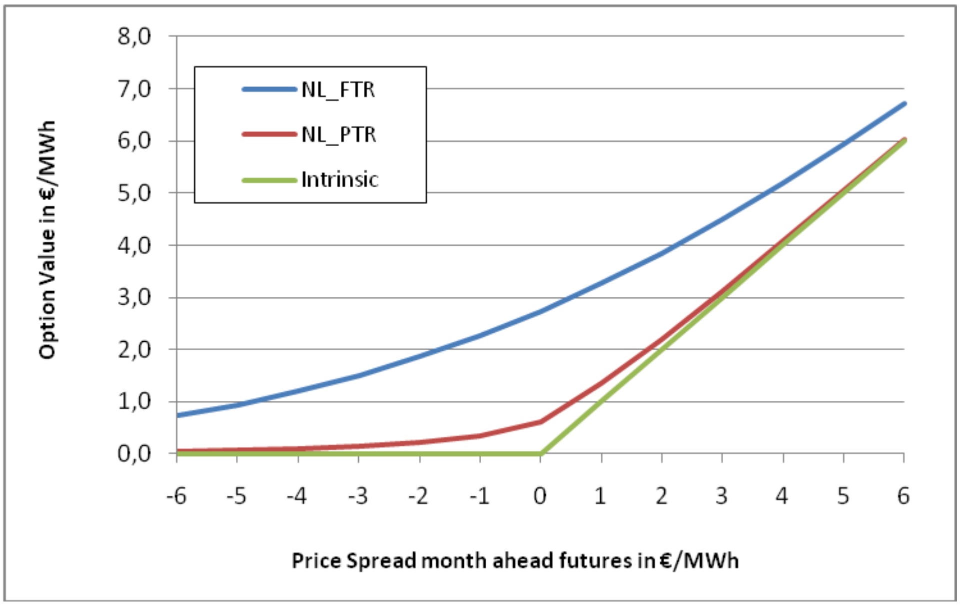

Figure 9 : Modeled values for PTR and FTR at the German/Dutch border for various spread levels.

5.2 Interpretation of results

Implicit allocation of transmission capacity as suggested in the Market Coupling process does add significant value to existing transmission capacity. In order to be able to capture this value within long-term auctions of transmission rights, TSOs would have to change the design of the option from a PTR (with exercise in the morning of d-1) to a FTR (with automatic exercise within the Market Coupling process).[18]

As any power transmission line provides the option to move electricity from A to B as well as from B to A, the TSOs simultaneously can sell two options within one auction. Assuming that the capacity is the same for both directions, we can assess the likely change in congestion rents they should be able to capture for firm and tradable PTRs and FTRs.

Taking the data for the German/Dutch border and assuming equality of forward prices in both markets (ATM-option), a TSO could capture for the ATM transmission spread option 4,47 times the value of (otherwise perfect) PTRs if he offered FTRs instead. Even if the forward spread is significant (say 3 €/MWh), it is advantageous to sell FTRs as they would be priced with a 44% premium in comparison to PTRs for the same interconnection.

Using the modeled values we can also compute the sum of income (from simultaneous selling the spread option from A to B as well as from B to A) for the TSO depending on the spread of forward prices as depicted in Figure 8.

[18] Kristiansen, Rosellon (2010) even show how such FTRs could encourage the integration of merchant investments in cross-border transmission capacity.

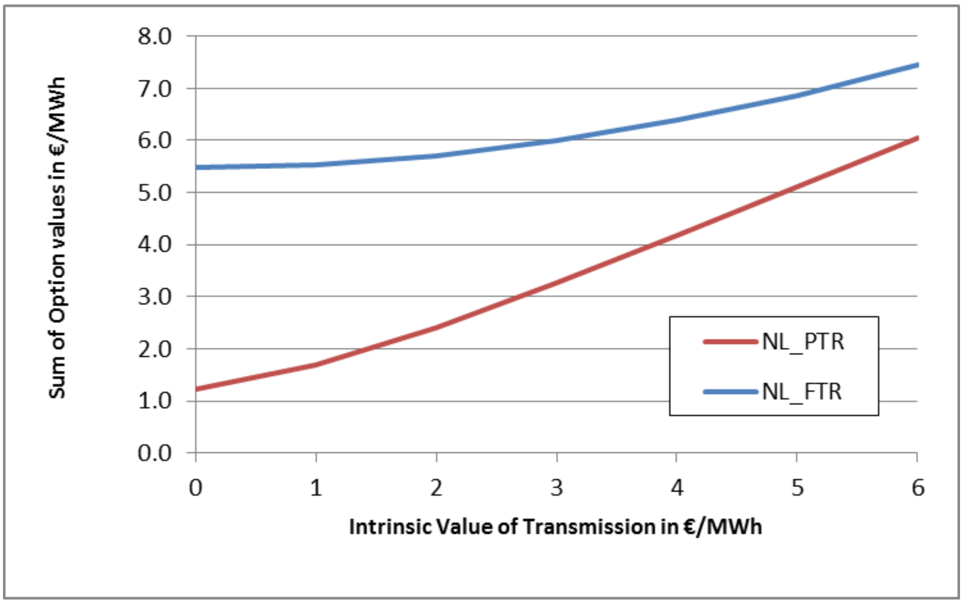

Figure 10: Modeled income from selling transmission rights as PTRs or FTRs for Dutch/German interconnection (sum of both directions)

The graph shows that the total income is higher when there is a significant spread in forward prices. With TSO´s holding a monopoly in transmission, we can conclude that there are no incentives in place for them to actually maximize the available transmission capacity. Making available more transmission with any given physical capability would tend to reduce the spread of forward prices providing less income per MWh transmission capacity sold and at the same time increases the TSO´s risk position. As we model "perfect" transmission spread options also in terms of firmness, they would have to compensate the owner (financially) in case actual usage is not possible. Moving from PTRs to FTRs appears to somewhat mitigate this issue, as the value of FTRs is significantly higher than PTRs when the forward spreads are low, but the shape of the curve is not altered. We believe that further research is required to better assess the risk position and incentive structure for TSO´s.

5.3 Bidding behaviour of traders

We now compare modeled results for PTR to prices paid in the auction for the respective months. Figure 11 graphically represents the findings with the observable bids. We do see that the bids tend to be between the PTR value and the intrinsic value and sometimes even at the intrinsic value of the option. As the number of market participants bidding for this capacity in a closed auction is significant and pretty stable, it appears very unlikely that the design of the process does allow participants to exercise market power. As we have modeled values representing "perfect" spread options, the gap has to be attributed to some form of discount, i.e. due to non-firmness and limited tradability of the option sold[19].

[19] An underlying assumption in basic modeling of the value of financial products is the assumption that positions can be opened and closed at no costs. In reality, this is not the case and transaction cost and risks of limited tradability are reflected in bid/offer spreads for products. Currently issued transmission rights are most commonly burdened with a number of features, making secondary trading of those rights impossible or very costly. There are e.g. registration requirements and fees as well as limitations to resell parts of the auctioned transmission right (such as all weekends). These restrictions are not reflected in the model used here to value the transmission spread option.

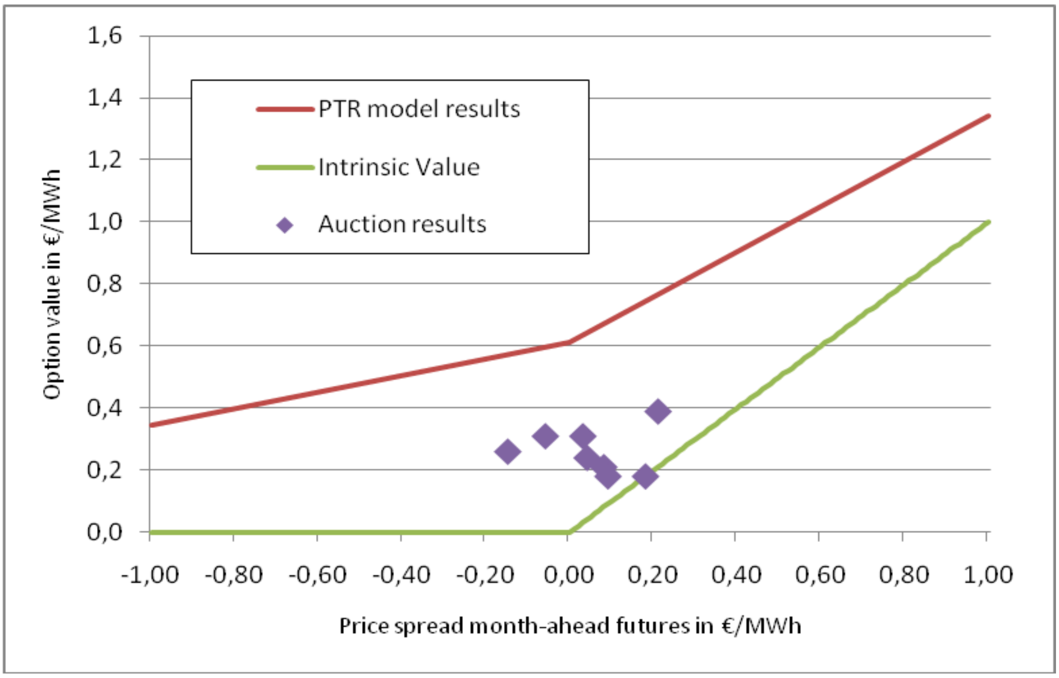

Figure 11: Modeled PTR values and prices actually paid in the auctions (November 2009 to September 2010).

We, however, can also conclude from the numbers that traders are willing to pay a premium above the intrinsic value reflecting in principle some time value of the transmission spread option.

6 Additional aspects

6.1 Transmission rights with intraday exercise

Access to hourly prices of the spot exchange is easy and provides a long time series. However, the market situation is not at all "frozen" from this point onwards and significant intraday activities are necessary in order to keep generation and demand balanced. While historically these intraday trading activities have been (on the continent) mostly bilateral or OTC, spot exchanges have addressed this market by introducing intraday trading platforms and, thus, providing more price transparency. In power markets, single hours for the delivery day are traded on a continuous basis. With the price of the day-ahead spot auction providing the starting point for a certain hour within the intraday period, prices can significantly change with the last traded price on the intraday platform being either below, at or above the settlement price of the day-ahead spot market. In order to visualize this effect, Figure 12 illustrates three time series of August 2010 power prices for single hours in the Austrian/German delivery area determined at three different times. [20] We see that the earliest price, i.e. the day-ahead auction result at Austria's power exchange EXAA determined at 10:15 a.m. (d-1), deviates from the EPEX day-ahead auction result, which is determined less than two hours later at 12:00 a.m. (d-1).

[20] Keep in mind that – because there is no structural congestion in cross-border transmission capacity – Austria and Germany do belong to the same delivery period. Thus, market participants are – independent of their physical location – able to trade in both countries equally.

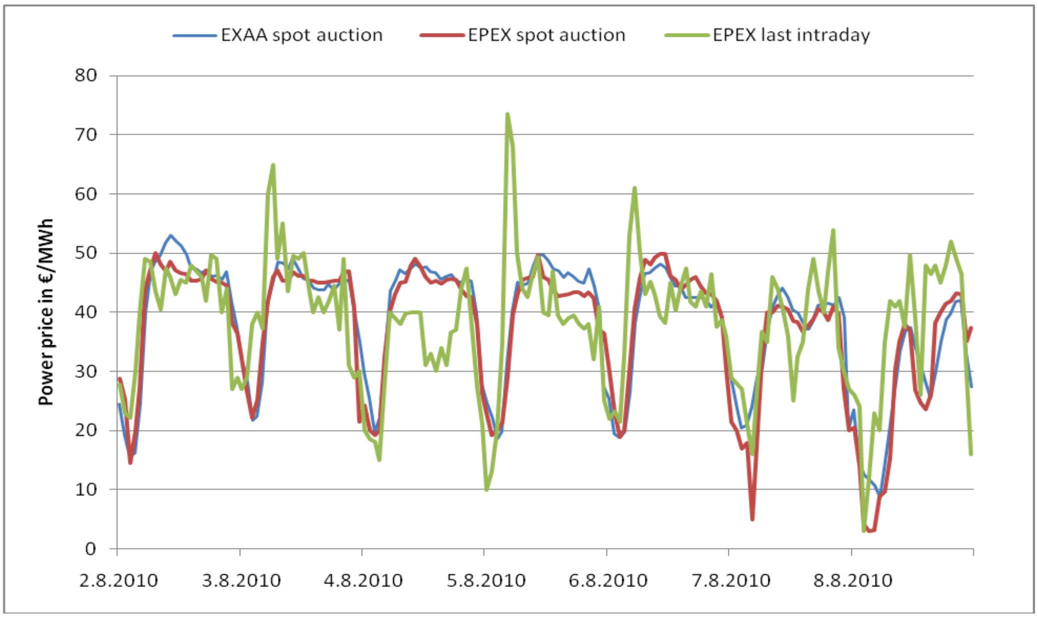

Figure 12: Hourly power prices in Austria/Germany during a week in August 2010.

Price spreads between regional markets might even be higher on an intraday basis, and one can assume that transmission spread options that can be exercised intraday would have an even higher value. In power markets, however, no transmission rights allowing for intraday exercise have been issued in Europe recently and, therefore, there is no history of prices achieved in auctions. It should be noted however, that formerly used long-term transmission arrangements (still in place at some borders) and gas transmission rights do allow for intraday (re-)nomination.

Long-term transmission rights have previously raised concerns about companies and countries shielding their markets against cross-border competition (or rising prices when exports are attractive). With these concerns in mind, Use It or Lose It provisions (UIOLI) were put in place for longer-term rights while intraday usage of transmission capacity would follow the First Come First-Served rules. One could imagine that those arguments might become less important over time and, thus, transmission rights with intraday exercise could be introduced. Given the principle of "non-discrimination", those rights would, however, need to be available to all interested market participants.

6.2 Reservation of transmission capacity for reserve and balancing

So far, there has been little interest in issuing transmission rights with intraday exercise. However, there is an ongoing debate if transmission capacity should be reserved for reserve and balancing purposes. With the balancing price spread being even higher and more volatile than hourly day-ahead or intraday prices, we can conclude that the option value of a transmission right defined accordingly should be highest.

However, cross-border real-time nomination between market participants would imply significant operational requirements on IT systems and add operational risks. Limiting such rights to TSOs while enlarging the relevant market for procuring reserve and balancing via reserved transmission capacity would clearly discriminate against all other market participants (which would have no access to such a right). In addition, the economic benefit of such reservations is questionable. Assuming balancing needs in both markets are stochastic and the provision of balancing energy is equally competitive, we can assume that the marginal asset able to supply – say positive – balancing energy can be expected to be cheaper in the market that has cleared at a cheaper hourly price (let us assume this is market A). If more transmission would have been available at a day-ahead stage, this unit would have produced power for the wholesale market and its production would have been exported to market B, lowering the wholesale market price there (and, thus, making also a cheaper asset available for positive balancing). Given the stochastic nature of balancing needs, transmission rights reserved for balancing purposes might not even get used at all, as there is no physical need to transport positive balancing power even if there is a significant price difference between the markets.

Thus, any transmission capacity that is withheld from wholesale spot and intraday markets will for sure hinder price convergence (and, therefore, reduce economic welfare) as long as prices differ. When reserved for potential usage to transport reserves, the capacity only can get used when positive balancing energy is required (say 50% of the time) in the more expensive area.

7 Conclusion

In modeling the value of transmission spread options, we did find evidence that the full potential value of transmission is not captured in the current design of transmission rights by TSOs. We used the time series for spreads of EoD prices for baseload and hourly spot price differences for power between Germany and the Netherlands from November 2009 to October 2010 to compare two modeled option values we named PTRs and FTRs. Our conclusion is that the requirement to exercise a transmission right early in the morning of d-1 (a product design we refer to as PTRs) has a severe negative impact on the option value. Changing the product design to a transmission right that would provide a cash-out equivalent to the hourly spot price differences (a design we refer to as FTRs) would significantly improve the value of the option. Such a change in design requires an effective market coupling process as has recently been implemented for the CWE region. The results show that moving from PTRs to FTRs becomes specifically relevant when price spreads in the forward markets are low.

In comparing the modeled value of the transmission spread option based on EoD prices (which is reasonably close to the current exercise requirements of transmission rights auctioned longer term) with the actual prices achieved in the auctions, we find a discount in actual payments if the option is in the money. That discount most likely cannot be attributed to exercise of market power from any market participant, but is rather a reflection of perceived risks of the transmission spread option associated to the “non-firmness” of the rights issued and the deficits of tradability in a secondary market in comparison to the assumptions applied in modeling the value. Improving the design of transmission rights in those aspects could actually reveal more of the real value embedded in the physical transmission asset. As an additional result, we have to conclude that TSOs might not have adequate incentives to maximize the available transmission capacity because high spreads in the forward market provide higher congestion rents to them. Changing the design of transmission rights from PTRs to FTRs does mitigate -but not eliminate- that concern. Further research is needed to address this issue as well as the risk position of the TSO when auctioning a larger proportion of the capacity for longer terms. Because the volatility of prices (and presumably also of price spreads) is highest in intraday markets, further research should also focus on the impacts of enabling an intraday exercise of transmission rights.

APPENDIX

Results for modeled values of Transmission Spread Option w/o jumps					
Strike	**NL_FTR**	**NL_PTR**	**Fr_FTR**	**Fr_PTR**	**Intrinsic**
-6	0,7294	0,0403	2,6568	0,6967	0
-5	0,9400	0,0624	2,9862	0,8560	0
-4	1,2023	0,0943	3,3634	1,0666	0
-3	1,5050	0,1446	3,7596	1,3240	0
-2	1,8645	0,2207	4,1673	1,6444	0
-1	2,2710	0,3452	4,6151	2,0145	0
0	2,7418	0,6135	5,0747	2,4538	0
1	3,2645	1,3424	5,6108	3,0022	1
2	3,8466	2,1943	6,1608	3,6063	2
3	4,4910	3,1269	6,7205	4,2807	3
4	5,1881	4,0781	7,3426	5,0318	4
5	5,9214	5,0435	7,9759	5,8368	5
6	6,7172	6,0183	8,6476	6,6780	6

Table 5: Modeled results for value of transmission spread options w/o jumps (D/NL and D/F).

Results for modeled values of Transmission Spread Option with jumps					
Strike	**NL_FTR**	**NL_PTR**	**Fr_FTR**	**Fr_PTR**	**Intrinsic**
-6	0,8543	0,0514	2,9290	0,8509	0
-5	1,0730	0,0775	3,2731	1,0620	0
-4	1,3343	0,1197	3,6207	1,3104	0
-3	1,6450	0,1834	4,0138	1,6188	0
-2	2,0077	0,2849	4,4390	2,0093	0
-1	2,4197	0,4733	4,8951	2,4582	0
0	2,8844	1,0066	5,3564	2,9827	0
1	3,4113	1,8553	5,8826	3,6182	1
2	3,9865	2,7525	6,4099	4,2701	2
3	4,6269	3,6905	6,9919	5,0212	3
4	5,3160	4,6418	7,5782	5,7957	4
5	6,0516	5,6249	8,2231	6,6474	5
6	6,8274	6,6069	8,9049	7,5314	6

Table 6: Modeled results for value of transmission spread options with jumps (D/NL and D/F).

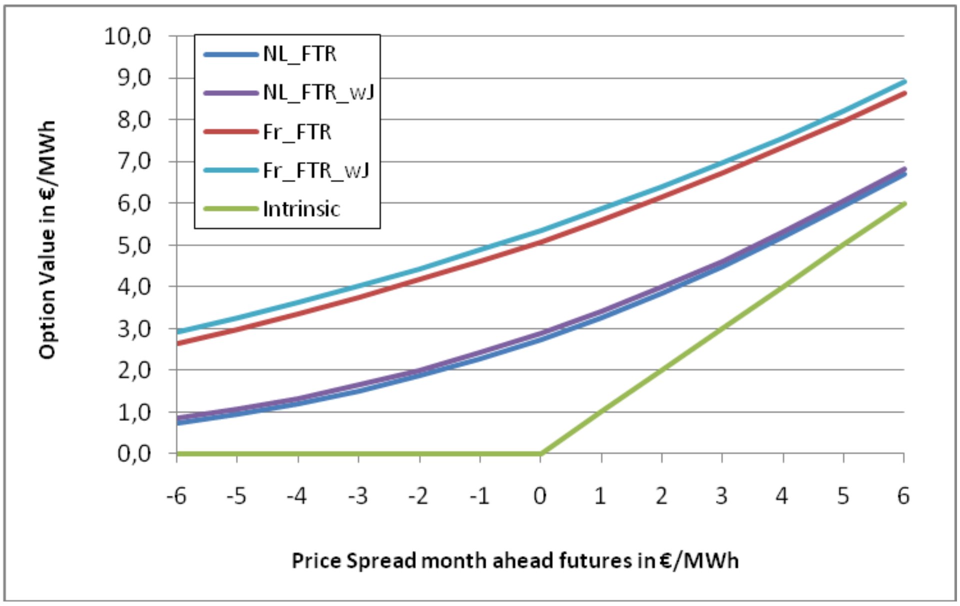

Figure 13: Comparison of modeled option values with and w/o jumps (D/NL and D/F).

REFERENCES

Adamson, S., Noe, Th., Parker, G. (2010). Efficiency of financial transmission rights markets in centrally coordinated periodic auctions. Energy Economics 32(4): 771-778.

Benth, F., Saltyte Benth, J. (2006). Analytical approximation for the price dynamics of spark spread options. Studies in Nonlinear Dynamics and Econometrics 10(3).

Benth, F.E., and Koekebakker S., (2008). Stochastic modeling of financial electricity contracts. Energy Economics 30(3): 1116-1157.

Black, F. and Scholes, M. (1973). The pricing of options and corporate liabilities. The Journal of Political Economy 81(3): 637-654.

Branger N., Reichmann O., Wobben M. (2010). Pricing Electricity Derivatives on an Hourly Basis. The Journal of Energy Markets 3(3): 1-59.

Carmona, R. and Durrleman, V. (2003). Pricing and hedging spread options. Siam Review 45(4): 627-685.

Deng, Sh.-J., Oren, Sh, Meliopoulos, A.P. (2010). The inherent inefficiency of simultaneously feasible financial transmission rights auctions. Energy Economics 32(4): 779-785.

Hikspoors, S. and Jaimungal, S. (2007). Energy spot price models and spread options pricing. International Journal of Theoretical and Applied Finance 10(7): 1111-1135.

Kristiansen T. and J. Rosellon (2010). Merchant Electricity Transmission Expansion: A European Case Study. DIW Discussion Paper 1028, July 2010, Berlin.

Lucia, J. J. and Schwartz, E. S. (2002). Electricity prices and power derivatives: Evidence from the nordic power exchange. Review of Derivatives Research 5(1): 5-50.

Margrabe, W. (1978). The value of an option to exchange one asset for another. Journal of Finance 33(1): 177-186.

Poitras, G. (1998). Spread options, exchange options, and arithmetic Brownian motion. The Journal of Futures Markets 18(5): 487-517.

Vukasovic, M., Apostolovic, M. (2009). A line-wise method for the allocation of physical transmission rights and its influence on physical and financial firmness. Proceedings of the 6th Internaltional Conference on the European Electricity Market (EEM), May 2009, Leuven, Belgium.

Wobben M., (2010). Valuation of Physical Transmission Rights - An Analysis of Cross Border Capacities between Germany and the Netherlands. Working Paper, online available at http://www.wiwi.uni-muenster.de/vwt/organisation/veroeffentlichungen/4_WP_Valuation_of_PTRs.pdf.