An options theory method to value Electricity Financial Transmission Rights

Dalia Patiño-Echeverri and Benoit Morel[1]

In deregulated electricity markets, members of today's electricity industry face financial risks that either did not exist or were not so significant in the former days of vertically integrated utilities. One example of these risks is the one associated to transmission congestion costs, which can be hedged with *Financial Transmission Rights* (FTRs).

Evidence that in the auction of annual FTRs in PJM, clearing prices included a "risk-premium" that "hedgers" paid to reduce the risk of highly volatile congestion charges, and "insurers" charged for bearing this risk, confirms the idea that hedging comes always at a cost, and motivates the questions of 1) how to find the value of these hedging instruments and 2) how efficient are the markets where these are traded.

The valuation of hedging instruments like FTRs posses a challenge because traditional methods to value financial derivatives do not directly apply. In this paper we extend the paradigm of options valuation to 1) Present, and apply a formula for the "fair value" of the premium of the FTR based on the probability distribution function of the corresponding *Congestion Charges.* 2) Argue that in PJM the lack of competition among insurers and the competition among hedgers increases the premium received by the former ones and paid by the others. 3) Argue that in PJM the higher the number of transactions for the same Point-to-point combination, the higher the premium paid by hedgers and received by insurers.

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1 Introduction

In deregulated electricity markets, members of today's electricity industry face financial risks that either did not exist or were not so significant in the former days of vertically integrated utilities, which has made *risk-management* become an important part of energy markets(Fusaro 1997). Managing the financial risk associated to the new conditions of the deregulated industry is a new challenge for participants, and a new world of opportunities for speculators. To value hedging instruments in this industry, and to assess the efficiency of the markets where these are traded, represents a challenge due to substantial differences between energy risks and other forms of financial risks for which hedging instruments have been developed(Pilipovic 1998). The underlying volatilities or the mere nature of the uncertainty to hedge against are sometimes not amenable to the valuation techniques developed in the context of the world of finance(Eydeland and Wolyniec 2003).

In this paper, we study an example of a risk that aroused with deregulation and for which hedging instruments cannot be evaluated with existing techniques: The risk associated to congestion costs. We address the question of how the theory of options can be used to determine the theoretical value of *Financial Transmission Rights (FTRs)*, the name with which instruments to hedge against transmission congestion are known in PJM Interconnection, the largest Regional Transmission Organization in North America. For a variety of reasons we discuss later, the theory of options in its present form cannot be applied meaningfully to estimate the value of that kind of hedging instruments, so we propose an extension that although tailored to the case of congestion costs, could be applied to a large range of other energy risks.

Transmission Congestions Costs and FTRs

In some U.S. Central Markets like PJM, an Independent System Operator (ISO) is in charge (among other tasks) of coordinating the spot market for electricity; collecting supply offers and demand bids from all generators and loads, and finding the optimal production schedule for each supplier. This optimal scheduling allows the calculation of the cost of providing or injecting the next MW at that particular node; the "Locational Marginal Price" (LMP) which is used to price the sales that occur through the spot market (See for example Stoft 2002, Part 5: Locational Pricing)

Due to the limited power flow capacity of transmission lines sometimes it is not possible to supply the electricity demanded with the cheapest generators and the ISO has to schedule generating units with higher production costs. The extra cost of scheduling an out-of-merit-order generator to supply electricity is the source of the transmission congestion cost (CC). If there were no transmission losses, nor transmission congestion, the LMP would be the same at every node of the electricity grid. With transmission congestion it is often the case that prices at the nodes of electricity withdrawal are higher -on average- than the prices at the nodes of electricity injection.

This difference in LMP is used to assign a monetary value to the cost of transmission congestion. The *Congestion Cost* (also referred to as Congestion Charge or Congestion Rents) between two nodes A and B (CC_{A-B}) is then, given by the difference between LMP at nodes A and B, or $CC_{A-B} = LMP_B - LMP_A$. These CCs are collected by the ISO that pays generators and charges Load Serving Entities (LSE) the LMP at their nodes. The money of CC is then allocated to the owners of the transmission capacity according to procedures that are specific to the different market designs implemented by different regions in the U.S.

In 1992 Hogan defined a system of Financial Transmission Capacity Rights that makes the holder indifferent between injecting power in one bus and withdrawing the same amount of power at another bus, or getting the corresponding "congestion payment" (Hogan 1992). Today after some debate of its relative convenience over flow-based rights (Chao, Peck et al. 2000) (Hogan 2000), Point-to-Point Obligation Financial Transmission Rights (FTRs) have become the most common way of capacity rights in the US Electricity Transmission Institutions. A transmission user is only required to hold one point-to-point FTR for any given amount of capacity, and as long as the points of injection and withdrawal hold, this single FTR provides a precise hedge. More specifically, point-to-point FTRs are defined for a given pair of withdrawal and injection points (sink and source nodes), for a specific number of MWs, for a specific type of hour (on-peak, off-peak, or 24 hour) and for a specific period of time (one month or one year in PJM). The holder of the FTR has the "right" to collect (and the duty to pay) the difference in LMP between the sink and the source during the period the FTR is defined for. For example one FTR in PJM for 1 MW between points A and B, for the peak hours during the month of October 2004 gave the holder the right to collect the difference in the Day Ahead LMP of nodes A and B for each of the 375 peak hours of October.[2] This sum of the differences in LMPs is called "congestion rents" of the FTR. $Congestion\ \ rents\, FTR_{A,B}^{october} = \sum_{i=1}^{375} LMP_B^i - LMP_A^i$.

Where i represents the i-th on-peak hour in October 2004.

If a market participant schedules a transaction that consists for example of injecting 100 MW at point A and withdrawing 100 MW at point B during every on peak hour of October then an $FTR_{A,B}^{october}$ for 100MW will provide her an exact hedge against congestion charges. The price

[2]In PJM on peak hours are hours ending 8:00-23:00 during weekdays (excluding FERC holidays).

this market participant pays for the 100 $FTR_{A,B}^{october}$ in the auction will be the entire amount she pays in congestion charges for the mentioned transaction.

Taken as a whole, FTRs represent both a right and a liability. Holders of FTRs have the right to receive the difference in LMP from the ISO when it is positive, but have also the obligation to pay the ISO when this difference is negative. In the majority of the cases, an FTR that produces negative rents is also sold at a negative price. This can be interpreted as if market participants who schedule transactions that create counter flow on congested lines were paid in advance for this service a quantity equal to the price of the FTR. An FTR sold at a negative price can also indicate that a speculator/insurer is bearing the risk on future transmission congestions in the counter flow.

The widespread use of FTR to manage transmission congestion[3], and the suggestion of using them as “payment” to investors in the transmission network (Hogan 1999; Joskow and Tirole 2004), makes necessary a careful examination of the performance of existing FTR markets. and the exploration of the questions 1)What is the value of an FTR? 2) How do FTRs value compare to selling prices? 3) What variables influence the value and the price of an FTR?

In this paper we take a closer look at the results of the auction of annual FTRs in PJM Interconnection, which has a market structure that most likely will be emulated in a large portion in the U.S.Power System (Joskow 2005). In the next section we show how in most cases hedgers pay a premium to hold FTRs and insurers charge that premium. In the third section we develop a mathematical approach to value FTRs. In the fourth section we use our result to suggest what the fair value of the FTRs traded in 2003-2004 was and compare it to the value actually

[3] FTRs exist in In New York ISO (with the name of (Transmission Congestion Charges (TCCs), in New England ISO, in Midwest ISO and in California ISO (Firm Transmission Rights).

paid/received by market participants. In the fifth section we explore the effect of liquidity, and competition in the prices of FTRs and in the last section we present our conclusions and final remarks.

2 Hedgers pay a premium for the FTRs while insurers charge a premium for the FTRs: Evidence from the Annual Auction in PJM 2003-2004

There are two empirical studies that we are aware of, that examine the recent performance of FTR markets. Using the data of all rounds of six-month TCC auctions in NY ISO for years 2000-2001, Siddiqui et al. (Siddiqui, Bartholomew et al. 2003)conducted an empirical comparison between what the purchasers of FTRs paid for congestion per MW with what purchasers would have paid had they paid the congestion costs directly instead of purchasing FTRs. Although most participants guessed correctly the direction of transmission congestion, they paid a premium for the FTRs, that seems excessive. Adamson and Englander (Adamson and Englander 2005) evaluated a database of one-month FTRs traded in 50 selected monthly auctions from November 1998 to April 2003, and concluded that "pricing in the NYISO TCC auction continues to be inefficient."

We made the same comparison of FTR prices vs Congestion Rents (CRs) for the PJM market using data publicly available[4] on the annual FTR Auction for the period June 1st 2003 to May 31st 2004 in which there were approximately 15,000 FTR transactions.[5] We find that although prices and payments of the FTR are linearly correlated (linear correlations are higher than 0.88 for all subsets of FTRs and 0.96 weighted average), there is a substantial difference

[4] PJM web site www.pjm.com contains data of the FTR annual and monthly auctions, and data of the Day-Ahead hourly LMPs to compute congestion costs or "rents".

[5] There are 3030+ nodes in PJM for which the Day Ahead LMP is reported. 683 nodes served as sources and/or sinks for FTRs traded in the Annual Auction 2003-2004. For 16 out of 683 there data on the LMP was incomplete or inexistent, so we couldn't find the congestion rents for 337 FTRs out of the 14,966 traded.

between the two. We also find that this difference between the price and the payment obtained in CRs in most cases represents a profit for those market participants that are paid in the auction to hold an FTR (they are paid in the auction more than what they have to pay in CRs), and an extra charge to those participants that pay to hold and FTR. In total, the amount of money paid by market participants who paid to hold obligation FTRs exceeded the amount they received in CRs by $4.8 million.

The fact that FTR prices deviate from CRs is to be expected. For market participants who need to back their electricity schedules, FTRs are a way to pay a fixed price for congestion instead of being exposed to volatile congestion costs. The reduction in risk provided by the FTR is valuable to this participants and that is why they pay for it. Similarly those market participants who are paid to hold an FTR, are paid in exchange for bearing the risk of uncertain future congestion charges.

We can define the *premium* as the difference between the price paid for the FTR and the rents received. If we call those who pay to hold an FTR “hedgers”, and those who are paid “speculators” or “insurers”, we find that in the analyzed auction hedgers often paid a premium, while speculators often got a premium, as the next table shows. The case of hedgers who bought FTRs for off-peak hours is an exception; in total, they got in CRs less than what they paid for the FTR.

	Total Paid in Auction by Market Participant ($)	Total Received in CRs by market participant (FTR holder) ($)	Paid – Received ($)	Paid-Received as % of Paid ($)
Total FTR obligations[6]	5.32E+07	4.84E+07	4.77E+06	
24h Price>0	7.22E+07	5.67E+07	1.55E+07	21%
24h Price<0	-1.94E+06	-8.76E+05	-1.07E+06	55%
On Price>0	9.62E+06	8.28E+06	1.34E+06	14%
lOn Price<0	-2.61E+07	-1.76E+07	-8.46E+06	32%
lOff Price>0	6.50E+06	6.79E+06	-2.98E+05	-5%
lOff Price<0	-7.14E+06	-4.87E+06	-2.28E+06	32%

Table 1: Annual FTRs (obligations) purchased by market participants in the PJM Auction for year 2003-2004

Next table shows that the premium paid had the right sign (positive for hedgers and negative for insurers) for most of the FTRs (measured as a number of transactions, and as number of MW) of each category. In addition, the average size of those premiums in the right direction is substantially bigger than the average size of the premiums in the wrong direction.

Type of FTR (obligation)	Num FTRs Prem>0	Num FTRs Prem<0	% FTRs with premium right direction	Num MW Prem>0	Num MW Prem<0	% FTRs with premium right direction	Min Prem	Max Prem	Ave W Pos Prem	Ave W Neg Prem	Relative size of average size of the premium in correct direction vs incorrect direction
24h Price>0	3,491	699	83%	16,043	3,953	80%	-19,767	16,957	3,947	-1,680	235%
24h Price<0	79	328	81%	222	1,306	85%	-33,056	4,351	1,361	-4,378	322%
On Price>0	877	824	52%	12,037	6,338	66%	-16,938	11,864	3,066	-1,185	259%
On Price<0	273	2,258	89%	1,038	8,955	90%	-17,227	15,474	1,211	-3,528	291%
Off Price>0	797	1,011	44%	8,603	6,433	57%	-12,159	6,648	959	-761	126%
Off Price<0	243	1,199	83%	801	4720	85%	-15,654	12,841	746	-1,623	218%

[6] Includes 44 FTRs purchased by market participants at price 0.

3 A Formula for the Fair Value of the Premium

In this section, we present a formula to value a contract (or an investment) that sets a limit on the losses of a party that faces an uncertain future payment. This formula, provides a risk neutral valuation of the hedging instrument (as does the Black Scholes formula (Black and Scholes 1973)), but it can be applied to a very large class of situations one encounters in the energy world and also outside. We determine the value of the risk-reducer-instrument (e.g. an FTR) by assuming that the buyer is willing to pay at the present the expected price (mean) of the future cost, plus a premium equal to the expected value of the gains that could get with the contract. The value of the premium is regarded as the value paid for an insurance policy against the uncertainty in the future cost, and in particular against the possibility of the future cost exceeding its expected value.

For the premium to be zero, the expected value of the potential losses of the buyer of the FTR (when the cost does not exceed its expected value), should be equal to the potential losses of the seller of the contract (when the cost does exceed its expected value). For those FTRs for which we can be sure about the sign of the congestion charges (so we know the direction of transmission congestion) the premium cannot be zero, because one of the parties (the seller) is facing a risk that the other one does not face (the buyer). The buyer's losses are limited by the price paid for the FTR while the losses of the insurer are not limited. This is why the buyer pays a premium over and above the expected value of the cost she wants to hedge against.

For those FTRs for which there is uncertainty about the sign of Congestion it makes more sense to buy an FTR OPTION, which provides the holder with the right to collect when CRs are positive, but does not imply a duty to pay when those CRs are negative. The method proposed in this paper deals only with FTR Obligations for which there is not uncertainty on the sign of congestion charges/rents. The uncertainty is only in the value of the congestion costs.

A financial instrument that reduces the risk associated with a future volatile cost C must be sold at a price P that exceeds the expected value of C by some premium. We can call this premium H, and write the following equation:

$$H(C,P) = P - \langle C \rangle \qquad \text{EQ.1}$$

If we can find another equation that relates the value of the premium *H*, the expected value of the cost $\langle C \rangle$ and the fair price of the financial instrument P, we can use it together with EQ.1 to find a solution for both *P* and *H*.

We assume that the buyers of the contract want to hedge against the possibilities of C being much higher than its expected value $\langle C \rangle$, by paying H. The premium paid has to be such that these buyers end up in a risk-neutral position. This means the value of *H* has to be equal to the expected value of the money the buyer will save with the hedging instrument (in other words, the insurance policy). The hedge holder (the buyer) will be "saving money" whenever C exceeds the value paid for the hedge. If the hedging instrument is paid at time t, the corresponding payment is received at time T, and the continuous interest rate is r, then the value of the hedging instrument H is:

$$H(C,P) = e^{-r(T-t)} \langle Max[0, C-P] \rangle \qquad \text{EQ.2}$$

EQ.2 is identical to EQ.2 of Bouchaud and Sornette (Bouchaud and Sornette 1994) who show in particular that when $f_c(c)$ is lognormal (the future price of a stock has a lognormal distribution), EQ.2 yields back the Black-Scholes formula to price a call option.

We can combine EQ.1 and EQ.2 to solve for the value of P:

$$P = \langle C \rangle + H(C, P) \qquad \text{EQ.3a}$$

$$P = \langle C \rangle + e^{-r(T-t)} \langle Max[0, C - P] \rangle \qquad \text{EQ.3b}$$

$$P = \int_{-\infty}^{\infty} c f_c(c) dc + e^{-r(T-t)} \int_{P}^{\infty} (c - P) f_c(c) dc \qquad \text{EQ.3c}$$

The last expression (where $f_c(c)$ denotes the probability-density-function (pdf) of C), can be solved numerically for P.

The assumption that the FTR price is higher than its expected value is justified by the fact that those market participants of PJM interested in buying FTRs, inevitably face uncertainty in the congestion cost C, and supported by the evidence that in fact they systematically pay more for the FTR than what they get in CRs.

A useful result derived from the formula presented above, can be found when looking for the value of the premium H when the cost C is normally distributed. Let $P_{normal}\left(\langle C \rangle, \sigma\right)$ denote the price that should be paid for an instrument that gives to the holder the right to collect C one year from now, with C being normally distributed with mean $\langle C \rangle$ and standard deviation σ. Assuming r = 0 (t = 0, and T = 1), EQ.3c can be rewritten as:

$$\langle C\rangle + \frac{1}{\sqrt{2\pi}\sigma}\int_P^{\infty}(c-P)e^{-\left(c-\langle C\rangle\right)^2/2\sigma^2}\,dc - P = 0 \qquad \text{EQ.4}$$

It can also be shown that

$$P_{normal}\left(k\langle C\rangle, k\sigma\right) = kP_{normal}\left(\langle C\rangle, \sigma\right), \qquad \text{EQ.5}$$

That is, the price increases in the same proportion as the changes in $\langle C\rangle$ and σ. This allows us to express the price that should be paid for the contract (as a proportion of the expected value of C), as a function of C's coefficient of variation. By replacing $k = 1/\langle C\rangle$ in the previous equation, we get:

$$\frac{P_{normal}\left(\langle C\rangle, \sigma\right)}{\langle C\rangle} = P_{normal}\left(1, \frac{\sigma}{\langle C\rangle}\right). \qquad \text{EQ.16}$$

Solving the previous equation numerically for P, we find that the relationship between the price that should be paid for the instrument as a proportion of the expected value of C, and the coefficient of variation of C, is linear as shown in the following graph:

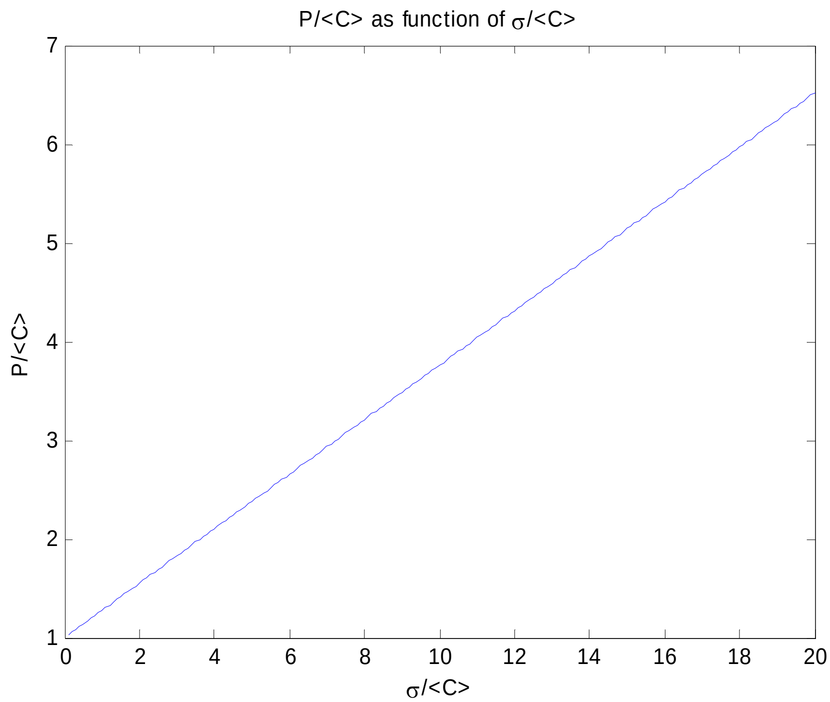

Figure 1. P/<C> as a function of σ/<C>

In this example we have,

$$\frac{P_{normal}(\langle C\rangle,\sigma)}{\langle C\rangle} \cong 1 + \frac{0.2760\sigma}{\langle C\rangle} \qquad \text{EQ.7a}$$

or

$$P_{normal}(\langle C\rangle,\sigma) \cong \langle C\rangle + 0.2760\sigma\,. \qquad \text{EQ.7b}$$

Replacing P in EQ.3a., we get that the fair value for the premium is $H = 0.2760\sigma$.

It is important to note that C represents a cost, and our method carries the assumption that $\langle C\rangle$ is positive. Describing C with a normal distribution implies that in theory C can take any value. If the expected value of C is positive, it makes sense for the agent facing this future cost to hedge against the possibility of C exceeding its expected value. The possibility of C taking a negative value should not worry this market participant because this will mean that the direction of Transmission Congestion will act in his favor and she will receive a “transmission congestion” payment for her energy transaction.

4 The fair value of an FTR in PJM

In this section we calculate the fair value of the FTRs traded in PJM and compare them with the actual price to assess the efficiency of this market. According to the formula presented in the previous section the value of an FTR is completely determined by the pdf of the corresponding Annual CRs. Finding the pdf of Annual CRs, requires a sample of CRs for several years which we do not have, because FTR markets have been operating for only a few years. Nevertheless we can use the data of hourly CRs to infer the pdf of annual CRs. We can find a way to express hourly CRs as a function of deterministic variables and random variables with known distributions, to simulate several years of hourly CRs as if they were different observations of the same year. Once we have each year realization, we find the annual sum and obtain a sample of annual sums from which we are able to derive a distribution.

We use three different approaches to model hourly CRs: 1) An Autoregressive Moving Average time-series model (Brockwell and Davis 1996) with one lag and a 24-hour seasonal component, with the value of *PJM hourly aggregated load* included as a predictor (ARMAX), with the errors determined by a General Autoregressive Conditional *Heteroskedasticity* (GARCH) model(Bollerslev 1986; Bollerslev 1987), 2) an ARMAX model like the one described in 1) but with residuals drawn from an empirical distribution, and 3) A model in which the CRs for each hour are represented with an independent variable drawn from one of 24 empirical distributions according to the month and hour class (on-peak or off-peak).

The modeling of hourly CRs with the methods mentioned above, and the simulations of 1,000 years worth of data for a sample of 45 selected paths, allowed us to obtain empirical distributions of Annual CRs for 24h, On-peak hours and, Off-peak hours. In all cases the histograms are symmetric, centered around the mean and resemble a normal distribution. According to the Jarque-Bera (Judge, Hill et al. 1985) goodness-of-fit test, the hypothesis that annual CRs for a 24 hour FTR follow a normal distribution cannot be rejected at the 5% significance level for most of the point-to-point combinations (Normality is rejected for 1 path under method 1), 4 paths under method 2) and 1 path under method 3). For method 3), the apparent normality of annual CRs is an expected consequence of the Central Limit Theorem CLT (Feller 1945).

As shown in the previous section, according to our formula, if the pdf of annual CRs is normal, the fair premium (relative to the expected value of these CRs) is a linear function of the Coefficient of Variation of the Annual CRs.

Using an estimation of the Coefficient of Variation of annual CRs (using approach 3) we get an estimate of the fair value of the premium of FTRs for each class (on-peak, off-peak, and 24 hours) and for each of the 3,766 “paths” for which there were FTR transactions.

When we compare our estimates of the fair value of the FTR (expected value of annual CRs plus premium) to the clearing price of those FTRs, we find that our estimates are systematically lower than the price observed in the market (paid by hedgers and, charged by insurers) as the two following graphs show. The only case in which the price observed in the auction is lower than our predicted fair price is the case of off-peak FTRs bought by hedgers. Hedgers paid only 90% of our estimate of the fair price of off-peak FTRs.

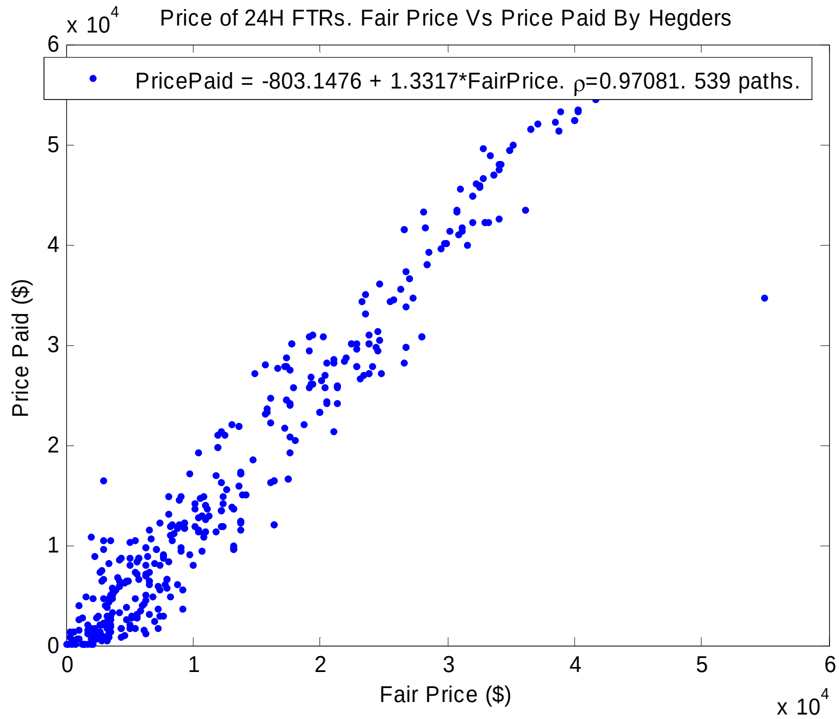

Figure 2. Fair Price vs Price paid by hedgers for 24h FTRs

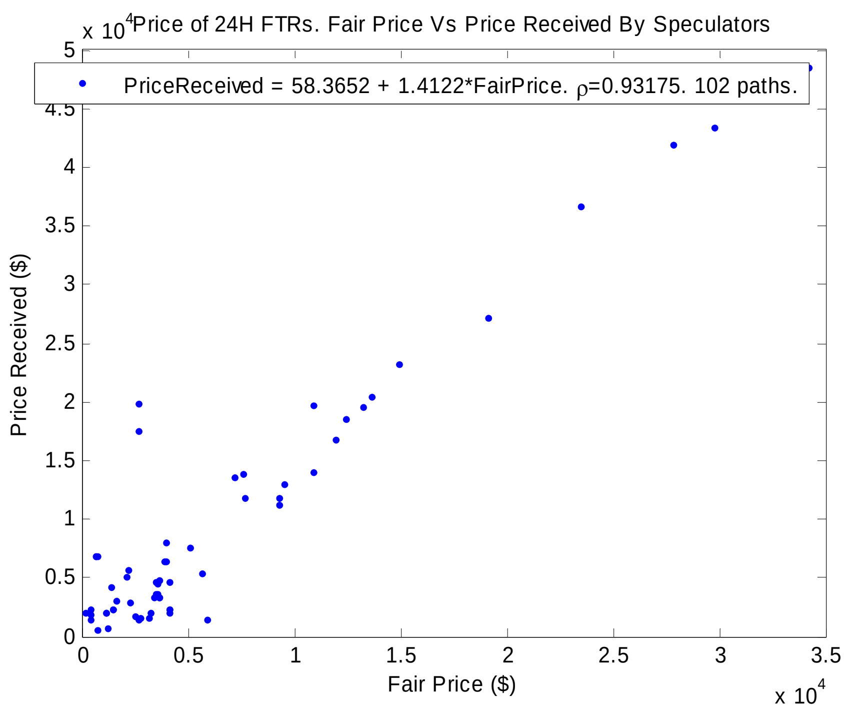

Figure 3. Fair Price vs Price received by speculators for 24h FTRs

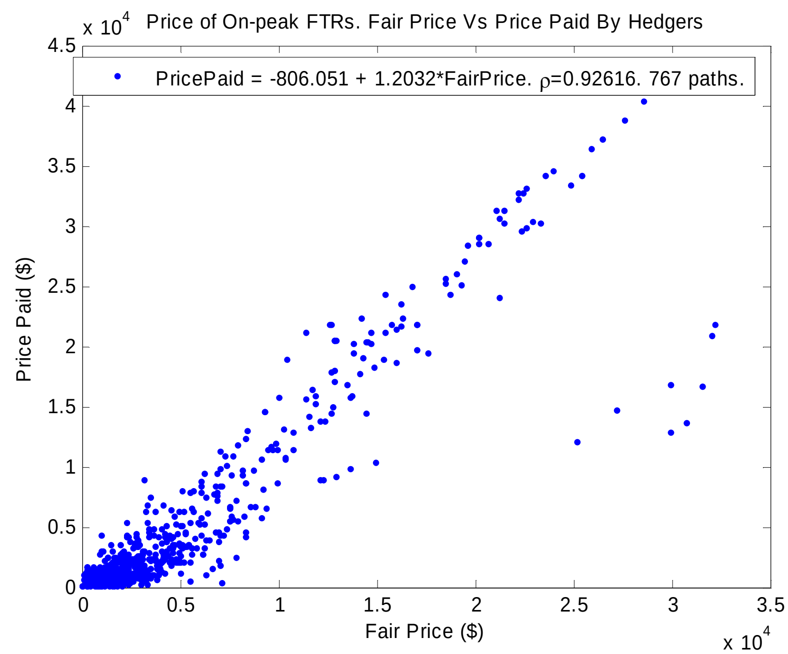

Figure 4. Fair Price vs Price paid by hedgers for on-peak FTRs

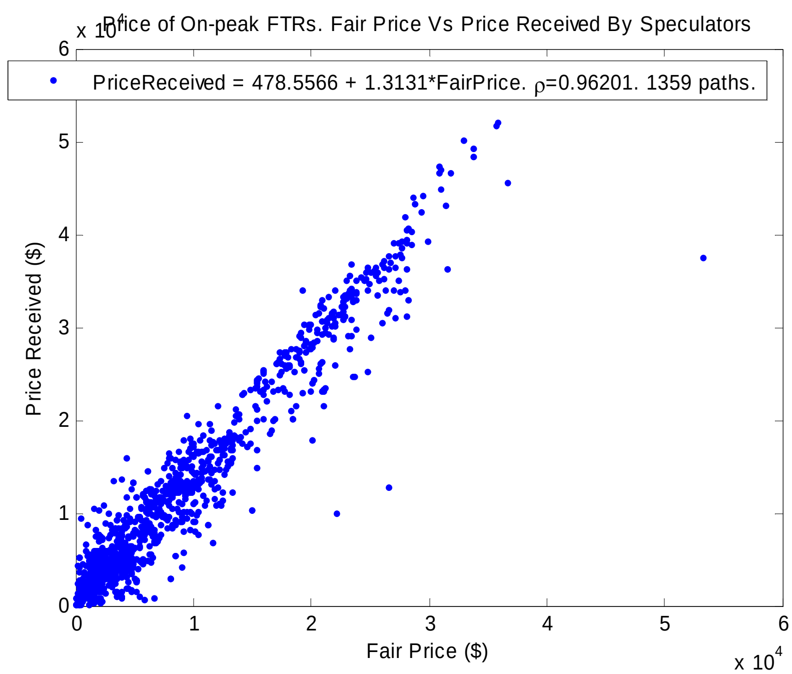

Figure 5. Fair Price vs Price received by speculators for on-peak FTRs

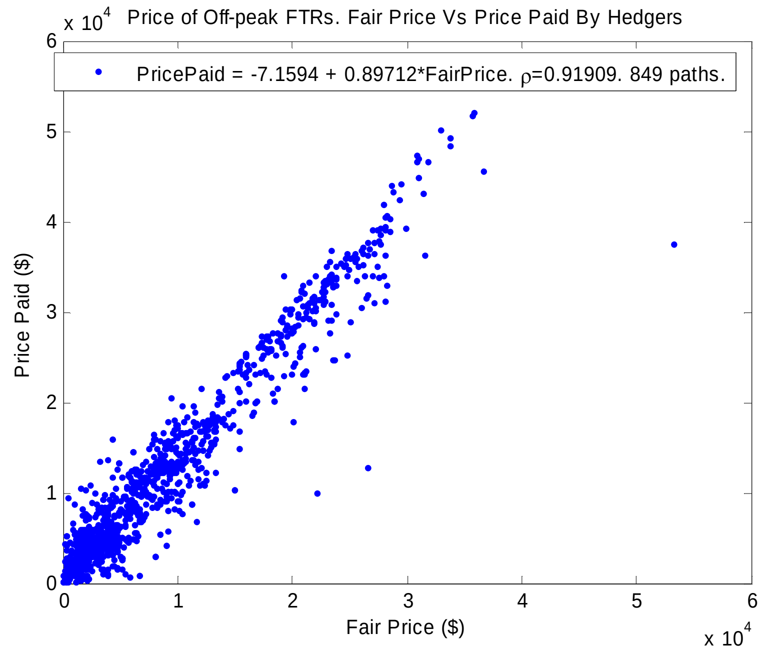

Figure 6. Fair Price vs Price paid by hedgers for off-peak FTRs

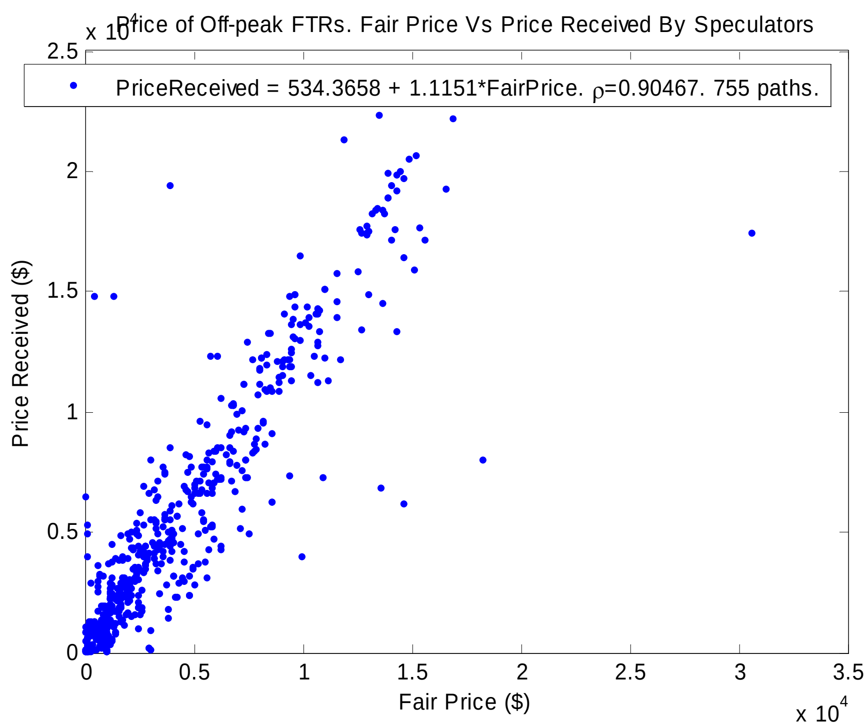

Figure 7. Fair Price vs Price received by speculators for off-peak FTRs

Several reasons can explain the discrepancy between our estimate of the fair price and the actual clearing price: 1)We might have underestimated the uncertainty of Annual CRs (the coefficient of variation), 2) Market participants might have overestimated this uncertainty, 3) Some competition among hedgers and lack of competition among insurers might cause a rise in the prices paid by hedgers and received by insurers, 4) FTRs might be seen by hedgers as protection against Monthly or even Hourly Congestion Charges instead of Annual –since LMP is made public every 5 minutes, participants in the wholesale electricity market can see the volatility of congestion charges at a very short time scale-.

In the following sections we conduct an analysis to assess whether some characteristics of the market, or the perception of FTRs by hedgers affect the clearing price of FTRs.

5 Assessing the effects of liquidity and competition on the FTRs premium in PJM

There are several reasons to believe that the discrepancy between the price paid for the FTR and the corresponding congestion rents (what we call the premium) is due at least in part to inefficiencies in the market (Deng, Oren et al. 2004) which are in turn explained by the novelty of this market, by low or inexistent competition for FTRs, by the winners course present in auction systems, and by the inherent difficulties that arise when trying to discover forward LMP prices (Siddiqui, Bartholomew et al. 2003; Adamson and Englander 2005).

In order to asses the effect that liquidity and competition in the FTRs market can have on the magnitude of the premium paid, we grouped FTRs by their point-of-injection (POI) and point-of-withdrawal (POW), calling each POI-POW combination a “path”, and conducted a series of linear-regression analyses to elicit the relative value of the premium (premium per MW divided by CRs per MW) as a function of the number of MWh traded, number of FTRs traded and number of participants involved.

The number of transactions can be an indicator of how liquid the market of FTRs for a particular path is. For those paths sold at a positive price, the amount of capacity sold and the number of participants involved is an indication of how much demand there is for a given path. It is important to acknowledge that a much better indication of how much demand there is for a path, would be the number of total bids. Cleared bids are only a portion of total bids (10% in PJM) and indicate not only how much demand there is for a path, but also how much capacity there is. Nevertheless, with this caveat, we continue to regard number of FTRs, number of MWh traded, and number of participants involved as good indicators of market liquidity and competition.

We hypothesize that the higher the competition among hedgers (higher number of participants and higher number of MWh sold), the higher the premium paid. We also hypothesize that with higher liquidity (higher number of FTRs traded) there are more opportunities for "price discovery" and the lower the premium. In fact, a market participant can present several bids for the same FTR (same path, and same class). Keeping everything else constant, with a higher number of FTRs traded there are more opportunities for price discovery.

In very few cases both hedgers and speculators traded FTRs for the same "path" (2% of the 3,933 paths[7]); most of the paths were traded exclusively by hedgers (63% of the MW capacity), or exclusively by speculators (17% of the MW capacity). Given the laws of physics that govern power flow, the offer of a speculator to bear the risk on one path, might affect the

[7] There were 166 "paths" for which market participants paid to have FTRs for a given direction and its counterflow. This means that in total there were 3767 combinations of nodes for which FTRs were traded.

price that a hedger pays for an FTR on another path[8]. In this sense, hedgers and speculators "interact" even if they do not trade FTRs for exactly the same paths.

The following table shows results of the linear regression analyses that explain the premium paid by hedgers, for those paths in which only hedgers participated and the average premium paid was positive, as a function of *Number of FTRs*, *Number of MWh traded*, and *Number of Participants* involved. For those paths sold only for the class 24h, both the *Number of FTRs* and the *Number of Participants* have coefficient estimates with the expected sign that are statistically significant (p-value < 0.05) and marginally significant (p-value <0.1) respectively[9]. For the paths sold only for peak hours, the estimated coefficients for the 3 explanatory variables have the expected sign and are at least marginally significant. For those paths sold only for off-peak hours, only the coefficient for the number of MWh has statistical significance.

Trade	Dependent variable	Num Paths	NumFTRs		NumMWh		NumPart	
			estimate	p-value	estimate	p-value	estimate	p-value
Only 24h	Prem 24P/CRs	245	-0.02645	0.0172	-5.82E-08	0.6043	0.0803	0.0569
Only On	PremOnP/CRs	123	-1.4591	0.0003	4.11E-05	<.0001	2.2115	0.0951
Only Off	PremOffP/CRs	171	-0.3791	0.2356	1.00E-05	0.0033	0.2407	0.8086

Table 2. Coefficient estimates for explanatory variables of the premium. Paths traded only by hedgers, for only one class, and where the premium paid was positive. Estimate of constant term is positive

For those paths sold for both 24 and peak hours, the three variables are statistically significant to explain the premium for 24 hours, and two of the variables are statistically

[8] Stoft 2002 pp207, states that " Sending power from X to fifty different locations will use fifty different amounts of the congested line.. one congested line in PJM produces 2000 different LMPs:" if prices of several locations are affected by congestion in one line, a bet on the value of the corresponding FTR has the potential to affects the values of other FTRs.

[9] All coefficient estimates and p-values measure Type III effects, that is the effect of each independent variable after the effects of the other variables have been taken in to account. (Used Proc GLM SAS/STAT 8.2). *Freund,* R. J., R. C. *Littell*, et al. (1991). *SAS System for linear Models*. *Cary, NC, SAS Institute Inc.*

significant to explain the premium for peak hours. In the other cases the coefficients are non significant.

Trade	Dependent variable	Num Paths	NumFTRs		NumMWh		NumPart	
			estimate	p-value	estimate	p-value	estimate	p-value
24 & On	Prem 24P/CRs	47	-0.0355	0.0052	2.42E-07	<.0001	0.1169	0.0253
	PremOnP/CRs	47	-0.0523	0.0015	6.95E-08	0.0877	0.2366	0.0007
24 & Off	Prem 24P/CRs	30	Not enough observations					
	PremOffP/CRs	13	Not enough observations					
On & Off	PremOnP/CRs	76	-0.0459	0.1272	3.21E-07	0.1693	0.1522	0.4222
	PremOffP/CRs	76	0.0283	0.3307	-1.92E-07	0.4201	0.0059	0.9631
24,On&Off	Prem 24P/CRs	31	0.0117	0.3645	-3.70E-08	0.5723	-0.1022	0.061
	PremOnP/CRs	31	0.0057	0.656	-8.52E-08	0.1924	-0.0072	0.8911
	PremOffP/CRs	14	Not enough observations					

Table 3. Coefficient estimates for explanatory variables of the premium. Paths traded only by hedgers, for more than one class, and where the premium paid was positive. Independent variables are totals. Estimate term is positive

For the paths sold only to speculators, we hypothesize that more competition (higher number of market participants, and higher number of MWh sold) would decrease the premium. We also hypothesize that a higher number of transactions (keeping the number of participants constant) implies that speculators have more opportunity to increase the premium, by making several bids for the same path and discovering how high the price can be.

The next table shows the coefficient estimates and the p-values for the regression equations that explain the average premium paid by speculators (a negative quantity) for a given path, as a function of the *Number of FTRs*, *Number of MWh*, and *Number of Participants*. The estimate of the intercept of the regression equation is negative in all cases. We expect the estimate of *Number of FTRs* to be negative, so it makes the premium more negative (speculators are receiving more money), and the coefficients of *Number of MWh* and *Number of Participants* to be positive, so the premium becomes less negative (implying that speculators receive less money). For those paths sold only to speculators for 24 h and where the average premium was negative (speculators on average guessed well the direction of transmission congestion), both *Number of FTRs* and *Number of Participants* have coefficient estimates that have the expected sign and are statistically significant.

Trade	Dependent variable	Num Paths	NumFTRs		NumMWh		NumPart	
			estimate	p-value	estimate	p-value	estimate	p-value
Only 24h	Prem 24N/CRs	53	-1.0976	<.0001	5.45E-07	0.7598	3.6769	0.0016
Only On	PremOnN/CRs	788	0.4126	0.4616	8.61E-06	0.5906	-0.6224	0.7463
Only Off	PremOffN/CRs	292	-0.3312	0.9227	1.02E-04	0.4191	-2.8549	0.7998

Table 4. Coefficient estimates for explanatory variables of the premium. Paths traded only by speculators, for only one class, and where the premium paid was negative. Estimate of intercept is negative

For the paths that were sold only to speculators for on and off-peak hours, the coefficient for *total number of FTRs* sold per paths is significant and has the expected sign in the regression equation explaining the premium for FTRs for on-peak and off-peak hours. The coefficient estimate for *Number of Participants* has the expected sign and is statistically significant for the regression equation that explains the premium for on-peak hours. The coefficient estimate *Number of MWh* is significant and has the expected sign in the regression equation that explains the premium for FTRs sold for off-peak hours.

For other categories of paths that were sold only to speculators for more than one class there are less than 30 paths and the regression analysis was not performed.

Trade	Dependent variable	Num Paths	NumFTRs		NumMWh		NumPart	
			estimate	p-value	estimate	p-value	estimate	p-value
On & Off	PremOnN/CRs	340	-0.2381	0.0085	-6.34E-07	0.3416	0.8577	0.0643
	PremOffN/CRs	340	-0.278	0.0068	1.31E-06	0.0834	0.5874	0.2637

Table 5. Coefficient estimates for explanatory variables of the premium. Paths traded only by speculators, for On and Off-peak hours

6 Fair value of FTRs if these are seen as protection against monthly or even hourly Congestion Charges

Treating FTRs as instruments to hedge against annual CRs seems reasonable because the payment for holding FTRs is in fact the annual sum of hourly congestion rents; however this is not the only possible way to look at these contracts. It is very likely, that because transmission customers are billed monthly, they might see annual FTRs as a bundle of hedges against 12 monthly congestion costs.

If we agree that it is reasonable to expect the sum of the variability of monthly CRs to be higher than the variability of annual FTRs, then we will agree that the fair price of FTRs when seen as protection against monthly CRs will be higher than when these are seen as protection against annual CRs. Under the framework of FTRs as insurance against 12 uncertain future costs, the fair price of an FTR Premium is given by:

$$P\left(f_{c_1}(c_1), f_{c_2}(c_2),.., f_{c_{12}}(c_{12})\right) = \sum_{i=1}^{12} P\left(f_{c_i}(c_i)\right)$$

Where $f_{c_i}(c_i)$ represents the probability density function of CRs for month *i* and $P\left(f_{c_i}(c_i)\right)$ is the value of an FTR that covers CRs for month *i*, given by equation 3. Furthermore we could see FTRs as protection against 24 different uncertain costs, for each hour-class (on or off-peak) and month.

Assuming the distributions of monthly CRs $f_{c_i}(c_i)$ are normal with means and std deviations equal to those observed for the corresponding months and hour class during the period 2003-2004, and using EQ.3 to calculate the fair value of the FTR, we get estimates of the FTR prices that are closer (but still lower) than the observed prices in the auction.

We could also argue that market participants see an annual FTR as a bundle of insurance policies one for each hour during that year, and therefore the variability of hourly Congestion Charges would be a better explanatory variable for the premium paid. We do not know what the variability of the congestion rents is for each hour, but we can test how the variability for all hourly congestion rents relates to the premium paid. We conducted a series of regression analyses, to assess the effects of the Coefficient of Variation of Hourly Congestion Rents on the premium paid for each "path", controlling by those other factors that we already know might affect the value of the premium, such as liquidity (Number of FTRs) and competition (Number of MWh and Number of participants).

The next box summarizes the results of the regression analysis for those "paths" sold only for Hedgers for 24 hours, for which the premium was positive (245 paths). As seen there, accounting for liquidity of the market and competition, the estimate of the coefficient for the Coefficient of Variation of hourly CRs is positive and statistically significant. This means that keeping liquidity and competition for a path constant, the ratio of the premium per MW to CRs paid by hedgers increases by 0.04 for each unit of increment in the Coefficient of Variation.

Dependent Variable: Prem24P_CRs Prem24P/CRs

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	30.39337992	7.59834498	31.13	<.0001
Error	240	58.58264529	0.24409436		
Corrected Total	244	88.97602521			

R-Square	Coeff Var	Root MSE	Prem24P_CRs Mean
0.341591	102.8287	0.494059	0.480468

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	0.3059198032	0.04960926	6.17	<.0001
NumFTRs	-.0218926501	0.00915033	-2.39	0.0175
NumMWh	-.0000000766	0.00000009	-0.82	0.4106
NumPart	0.0742147329	0.03481247	2.13	0.0340
CoeffVar_HouCRs	0.0414107271	0.00393718	10.52	<.0001

Table 6. Results Multiple Regression Analysis for those paths sold only to hedgers, for 24 hours. Only paths with positive premium were included in the analysis.

A similar analysis for those paths sold only to speculators for 24 hours show the same effect of the variability of hourly CRs on the value of the premium. The premium received by speculators increases with the coefficient of variation of hourly CRs[10]. It is important to note that for those paths traded only for 24h, the effect of the Coefficient of Variation on the premium received by speculators is more than 4 times the effect of the same variable on the premium paid by hedgers (abs(-0.1697) vs abs(0.0414)).

Dependent Variable: Prem24N_CRs Prem24N/CRs

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	329.2605851	82.3151463	23.55	<.0001
Error	48	167.7621718	3.4950452		
Corrected Total	52	497.0227570			

R-Square	Coeff Var	Root MSE	Prem24N_CRs Mean
0.662466	-96.21732	1.869504	-1.943002

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-2.002430132	0.78170849	-2.56	0.0136
NumFTRs	-0.367128219	0.20057030	-1.83	0.0734
NumMWh	0.000000528	0.00000123	0.43	0.6707
NumPart	2.610466395	0.77949521	3.35	0.0016
CoeffVar_HouCRs	-0.169716635	0.02329810	-7.28	<.0001

Table 7. Results Multiple Regression Analysis for those paths sold only to Speculators and only for 24h. Only Paths with negative premium

The effect of the coefficient of variation on the premium paid by hedgers, for those paths sold for both 24 hours and on-peak hours is positive and significant, so the higher the coefficient of variation, the higher the premium paid.

Dependent Variable: Prem24P_CRs Prem24P/CRs

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	5.59751879	1.39937970	59.11	<.0001
Error	42	0.99439332	0.02367603		
Corrected Total	46	6.59191211			

R-Square	Coeff Var	Root MSE	Prem24P_CRs Mean
0.849149	32.01655	0.153870	0.480596

Parameter	Estimate	Standard Error	t Value	Pr > |t|

[10] As before, increasing the premium received by speculators means making it more negative. Therefore the coefficient estimate for the Coefficient Of Variation of hourly CRs is expected to be negative, as it is in fact.

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	0.1593371313	0.04153330	3.84	0.0004
NumFTRs	0.0060253142	0.00914509	0.66	0.5136
NumMWh	-.0000000742	0.00000004	-1.71	0.0943
NumPart	-.0566835130	0.03822750	-1.48	0.1456
CoeffVar_HouCRs	0.1175171873	0.01441594	8.15	<.0001

Table 8. Results Multiple Regression Analysis for those paths sold only to hedgers, both for 24 and on-peak hours. Only Paths with positive premium were included in the analysis

The effect of the coefficient of variation on the premium paid by hedgers, for those paths sold for both 24 hours and off-peak hours is negative and significant, so the higher the coefficient of variation the higher the premium received by speculators.

Dependent Variable: Prem24P_CRs Prem24P/CRs

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	2.24901510	0.56225378	11.33	<.0001
Error	25	1.24092571	0.04963703		
Corrected Total	29	3.48994081			

R-Square	Coeff Var	Root MSE	Prem24P_CRs Mean
0.644428	61.81643	0.222794	0.360412

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-.1469364850	0.17375652	-0.85	0.4058
NumFTRs	0.0228357581	0.01550297	1.47	0.1532
NumMWh	0.0000000276	0.00000003	0.97	0.3419
NumPart	-.0789762038	0.05626472	-1.40	0.1727
CoeffVar_HouCRs	0.1706192738	0.02913114	5.86	<.0001

Table 9. Results Multiple Regression Analysis for those paths sold only to hedgers, for both 24 hours and Off-peak hours. Only paths with positive premium were included in the analysis.

7 Conclusions

In this paper we have presented evidence that the price of an FTR includes a premium that hedgers are willing to pay to reduce the risk of Congestion Charges, and “insurers” charge to bear such risk. We proposed that the price of an FTR should be equal to the expected value of the corresponding Congestion Rents plus the expected value of the “gains” of having such FTR (the expected value of the difference between Congestion Rents and the price paid for the FTR, when this difference is positive).

One challenge in finding the risk neutral value for a hedging instrument is determining the PDF of the variable to hedge against. In the case of FTRs, the PDF has to be reconstructed out of limited information. This is partially due to the fact that FTRs have been introduced recently and there is no much historical data. But the uncertainty on congestion costs will always be difficult to estimate as from one year to the next the pattern of congestions changes. We try to show that the lack of data to infer the pdf of Annual CRs can be overcome –at least in part- by analysing hourly CRs and simulating several years worth of data. Our empyrical analysis using this approach gives estimates of the price of the FTR systematically lower than the prices observed in the auction.

Our analysis for most classes of FTRs backs the hypotheses that competition among hedgers raises the value of the premium they pay, competition among speculators lowers the value of the premium they charge, and liquidity of the market lowers the premium paid by hedgers but raises the premium paid by speculators.

Our analysis also indicates that it is possible that annual FTRs are seen not as insurance against an uncertain annual payment, but as a bundle of insurance contracts against uncertain montlhy or even hourly payments.

The fact that agents that do not participate in the wholesale electricity market, act as insurers and profit from the trading of allowances constitutes an extracost in deregulated electricity markets, that did not exist before. The money paid in insurance against congestion charges leaks from the system, and does not come back to alleviate transmission congestion.

FTRs are only one example of hedging instruments in energy markets, and our method can be used to value other hedging instruments. Our formula, which in a sense generalizes Black Scholes represents only one step; the second which is at least as challenging is to find an algorithm which provides an acceptable estimate of the PDF of the variable to hedge against. Why tried to show with the example of FTRs that this is not impossible.

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