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THE RELATIONSHIP BETWEEN DAY-AHEAD AND FUTURES PRICES IN THE ELECTRICITY MARKETS: AN EMPIRICAL ANALYSIS ON ITALY, FRANCE, GERMANY AND SWITZERLAND

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The relationship between day-ahead and futures prices in the electricity markets: an empirical analysis on Italy, France, Germany and Switzerland

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Abstract

We evaluate the relationship between electricity day-ahead and future prices following the hedging pressure theory, which explains the difference between future prices and expected spot prices in terms of market players' risk aversion. We calculate the sign and intensity of the risk premia ex-post in the electricity market of Italy, France, Switzerland and Germany during the last decade and for all products traded, namely, monthly, quarterly, yearly futures and distinguishing between base-load and peak-price futures. We show that in all the countries there is no convergence of future prices to the underlying day ahead ones; moreover, for most of future contracts, the premium rises as contracts approach the delivery. For Italy and Switzerland this means that an inversion of the sing occurs, since on average risk premia are negative at the beginning of the trading period but become positive as the delivery period approaches. The hedging pressure theory implies that in these Countries premia are on average paid by power producers at the beginning of the period and by suppliers (i.e. power buyers) when coming close to the delivery. On the contrary, in France and Germany risk premia are both positive at the begging and at the end of the trading period, signaling that on average buyers are relatively more risk averse during the whole trading period. In addition, when considering the duration of the delivery period, contracts with longer delivery periods have, on average, higher negative risk premia.

Keywords: *electricity, prices, futures, spot, risk premium.*

J.E.L. Codes: D46, G12, G13, L94, Q41

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1. Introduction

The high volatility, the existence of a strong component of mean-reversion, and the presence of sudden and huge price spikes are well-known characteristics of wholesale electricity spot prices (Knaut and Paschmann, 2019 ; Li et al., 2016). These features are due to power limited storability and load fluctuation.

Sellers (i.e. power producers) and buyers (i.e. final customers' suppliers) of electricity can hedge risks by exchanging future contracts in organized markets, such as the ones managed by European Energy Exchange (EEX) for central European countries (Germany, Austria, France and Switzerland), and GME for Italy. Electricity futures are derivatives that fix the price ahead of the delivery period. During the trading periods, market participants exchange standardized contracts composed of a unit of energy (one MWh). The latter is going to be delivered to the buyer by the seller at the exchange price for the whole delivery period, for the contracts with physical settlement. On the contrary, a cash settlement is foreseen based on the difference between the spot and the forward price for financial contracts, which are indeed the majority of future contracts exchanged in the above-cited markets.[1] There exist several types of standardized contracts. At the EEX, for instance, electricity futures are traded for delivery periods equal to one week, one month, one quarter and the entire year. In addition, the delivery can refer to the whole period, or just a subset of hours throughout the period. The former are termed base-load contracts, while the latter peak-load, since delivery ranges from Monday to Friday, 8:00 a.m. to 8:00 p.m.

The limited storability of electricity means that the classic approach used for financial forward evaluation, i.e. non-arbitrage condition, cannot be applied. Electricity cannot be sold short; it cannot be purchased at the spot price today, stored it for a certain period of time and resold it at the forward price. Moreover, the classical concepts of convenience yield and cost of carry, that explain the relationship between forward and future prices, loose their meaning here, since they imply that traders can acquire and store the underlying asset (Hoff and Mortensen, 2014).[2] On the contrary, according to the hedging pressure approach (see Hendrik Bessembinder, 1992), the forward price of a certain asset can be read as the sum of the expected spot price on that asset and the risk premium. The latter is paid by the risk-averse operator in order to transfer the price risk to the counterparty. Both electricity producers and buyers may be interested in incurring an additional cost to cover themselves from price risk. This would result in both positive and negative risk premium (Pietz, 2009). In particular, a positive premium, namely, a positive difference between forward and expected spot price, would signal that buyers are relatively more risk averse than sellers, and therefore are willing to buy electricity forward at a premium compared to the spot. Doing so, they can guarantee themselves a fix price, transferring the risk due to spot price volatility to sellers. On the contrary, a negative premium, i.e., a forward price lower than the expected spot, implies that sellers are willing to pay a premium to buyers in order to transfer them the risk of spot price volatility.

There is a growing literature on the relationship between electricity forward and spot prices,[3] starting from the seminal paper of H Bessembinder and Lemmon (2002). Focusing on prices in the American PJM and California Power Exchange, these authors showed that the risk premia depend on the price volatility (and the skewness of spot prices), tend to increase as delivery period approaches and is

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[1] In the EEX the physical fulfillment is available only for weekly and monthly contract for German, Austrian, France, Dutch, Swiss, Belgian and GB power futures. The other contracts have a cash fulfillment. More information are available on www.EEX.com.

[2] An exception is for countries that have an electrical system based entirely (or almost) on hydroelectric power plants. In this case, prices are driven by the current and expected availability of the water resources and the convenience yield can be represented by water reserves stored in tanks. For an analysis of the Nord Pool, see (Botterud, Kristiansen, and Ilic 2010)

[3] A general survey about electricity derivatives with a focus on electricity futures is provided by (Aid 2015).

negative when expected demand is low. Several scholars have followed such an approach, yet providing discordant evidence about the sign and behavior of risk premia in future markets. Shawky, Marathe, and Barrett (2003) studied daily futures contract, for the years 1998 and 1999, traded in New York Mercantile Exchange market 6 months before the delivery and find a positive relationship between spot and futures prices. Lucia and Torró (2011) analyze weekly contracts of NordPool market during 1997-2007. They find that on average ex-post risk premium was positive and seasonal. Similarly, Junttila, Myllymäki, and Raatikainen (2018) find that risk premia of monthly products in Finnish market from 2006 to 2016 seems to vary between seasons but are positive on average. Other scholars, on the contrary, find both positive and negative values for risk premia. Handika and Trueck (2013) studied the risk premium ex-post of quarterly and yearly futures contract in the Australian regional markets from 2000 to 2012. The find that risk premium was positive on average but they record a strong impact of seasonality causing negative risk premium for quarters related to summer and winter while positive risk premia for spring and autumn quarters. Cartea and Villaplana (2008) study the risk premium in PJM, England and Wales, and Nord Pool markets and find that in PJM and E&W markets there are periods in which forward premium achieves negative values. Kolos and Ronn (2008) estimate positive risk premiums for the German EEX market and negative for the US PJM market. Furió and Meneu (2010) consider the monthly contracts for Spanish from 2003 to 2008. They find that two subperiods exists: before 2006 the mean forward premium was negative while after 2006 it was positive. In the Italian market Casula and Masala (2020) find that monthly futures contracts risk premium between 2011 and 2016 were negative on average while Falbo, Felletti, and Stefani (2014) have studied risk premia in the same market between 2008 and 2013 and find a positive value. Bevin-McCrimmon et al. (2018) focus on New Zealand market and study the relation between risk premia of quarterly futures contracts and market liquidity for the period from 2009 to 2015. They showed that for contracts exchanged two years ahead risk premia reduce as liquidity increases.

In this work we follow this stream of literature, performing a comprehensive analysis of the risk premia in four large European markets, namely, Italy, Germany, France and Switzerland. We study the relationship between spot and forward prices in these electricity markets in order to quantify and evaluate the risk premia for all forward contracts exchanged in these markets in the last decade, namely, from 2010 to 2019. In order to carry out the task we follow an ex post analysis of risk premia, namely, we study whether and how the future price have converged or not to the realized average spot prices that have been observed for the delivery period, per each type of product traded, monthly, quarterly and annual.[4] We investigate if and by how much the risk premia depended on the length of the contracting period, and the delivery duration; moreover, motivated by the undecisive results about the sign of the risk premia, we also investigate if a change in the sign of the premia is observed when comparing the beginning of the contraction period and the end of the exchange period. The latter would indicate that the need to cover risks shifted across market participants as contracts approach their maturity.

The paper is organized as follows. In Section 2, data is presented and discussed. Section 3 presents the formal definition of risk premium that we employ here as well as the empirical strategy followed. Results are presented and discussed in Section 4, and conclusion follow in Section 5. Further analyses and data are available as supplementary material.

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[4] At EEX, also daily and weekly futures are exchanged for Italy, France, Germany and Switzerland. Usually the trading of these products start at most one month before the delivery. We do not include them in our study since their period of exchange is too short and does not allow to perform a comprehensive analysis of the behaviour of the risk premia overtime during the exchange period.

2. Data

In electricity markets, electricity is traded on an hourly base, the day before the delivery; thus, the prices are termed day-ahead prices. Future prices are traded continuously (during market opening times) every day before the delivery. In this work, we consider daily base-load and peak-load futures quotations at the daily settlement prices of futures exchanged at EEX platform[5] for Italy, France, Germany and Switzerland. For the prices of the underlying, we consider the daily average day-ahead hourly prices. Time series considered starts from the beginning of 2010 to the end of 2019. All contracts are quoted in Euro/MWh. The minimum daily price fluctuation is set to 0.01 €/MWh while there no limits on maximum price fluctuation. At EEX, for monthly and yearly contracts, the trading always terminates on the business day before the first day of the delivery, while the trading for monthly contracts continue till the end of the delivery period.

Each future contract exchanged refers to a Country, a type of power delivered, namely, base-load or peak-load (for Switzerland just baseload contracts are exchanged), and a delivery period (either a month, a quarter, or a year). Monthly products are denoted by the first three letters of month and the year of the delivery (for example FEB-18), quarterly products are denoted by Q followed by the number of quarter they refer to and the year of the delivery (for example Q3-15), and yearly products are referred as CAL followed by year of the delivery (for example CAL-17).

Our dataset contains data of daily settlement prices for each contract, from the starting of trade until the last day before power delivery.[6] Note that the starting of trade depends on the contracts themselves. For EEX, monthly products are exchanged starting from 9 months before the delivery, quarterly products from 11 full quarters and yearly products from 9 years before delivery. The dataset includes also daily data on the open interests[7] for all contracts considered. It is important to note that in each trading day more than one product for a future delivery day can be exchanged.

The final dataset analyzed is composed by 166.526 observation for 936 contracts:
- 141 monthly, 45 quarterly and 10 yearly contracts for Italy;
- 196 monthly, 64 quarterly and 16 yearly contracts for France;
- 257 monthly, 89 quarterly and 21 yearly contracts for Germany[8];
- 72 monthly, 20 quarterly and 5 yearly contracts for Switzerland.

Day-ahead time series contains 374.783 hourly observations for each of the countries we consider. Table 1 contains descriptive statistics of day-ahead and future prices for all countries considered. We observe very high volatility with spikes which can also be negative. Spikes are usually caused by exogenous factors which cause an electricity supply deficit that cannot be filled with existing power capacity; this in turn will cause a sudden and massive increase in the price of electricity. Negative spot prices are due to load reduction and rigid supply with non-convexities in the cost functions (Cretì and Fontini, 2020). When this happens, buyer receive both electricity and money from the producers.[9] For Italy prices refer to the so-called PUN ("Prezzo Unico Nazionale" – single national price, in

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[5] See http:// www.EEX.com

[6] We do not include in our data the future prices of monthly contracts traded during the delivery period since we focus on the comparison between forward prices and expected ones before the day of the delivery.

[7] Open interests are a market liquidity measure. They represent the total number of futures contracts for a given product that have not yet been closed out.

[8] Before 2017 there was only one electricity futures market for Germany and Austria, i.e. Phelix Power Futures. After that date EEX launched two different power futures for the domestic Austrian market area (Phelix-AT Power Futures) and German market area (Phelix-DE Power Futures). In our analysis we used, as reference price for the study of Germany, the Phelix Power Futures a before 2017 and subsequently the Phelix-DE Power Futures.

[9] Negative electricity prices have administratively set lower limits. In the Italian power exchange, the lower bound of prices is zero, namely, negative prices are not allowed.

Italian). The PUN is paid by buyers, and is constructed as the weighted average of zonal prices that power producers receive in each of the six price zones that compose the Italian power market.

	ITALY		**FRANCE**		**GERMANY**		**SWITZERLAND**	
	Spot	***Futures***	***Spot***	***Futures***	***Spot***	***Futures***	***Spot***	***Futures***
Mean	55.2	54.91	41.07	49.12	41.68	44.61	48.01	42.76
Standard dev.	17.19	10.53	18.79	14.44	22.85	13.09	21.62	12.18
Median	53.22	53.89	39.39	47.76	38.99	43.82	45.29	41.03
Minimum	0	0.01	-200	0.01	-500	0.01	-49.95	20.17
Maximum	324.2	99.95	874.01	259.25	1399.99	93.9	553.88	100.5
Skewness	0.82	0.2	4.81	1.88	5.55	0.39	1.87	0.73
Kurtosis	2.65	1.8	175.83	13.6	192.81	-0.29	17.96	0.19

Table 1 Descriptive statistic for each country.
Time periods of spot prices are as follows: for Italy from July 2012 to January 2020; for France from January 2013 to January 2020; for Germany from February 2005 to January 2020 and for Switzerland from December 2006 to January 2020. Time periods of futures prices are as follows: for France and Germany from 2010 to 2019 while for Italy and Switzerland from 2014 to 2019.

Figure 1 reports an example of typical paths of futures prices of a given product compared to spot prices. A series of different features emerge: electricity futures prices shows a lower volatility, no mean-reverting process and an absence of spikes compared to spot ones. On the contrary, the spot prices exhibit a clear mean-reverting behavior. Moreover, note the huge negative spot price that occurred in the observation period.

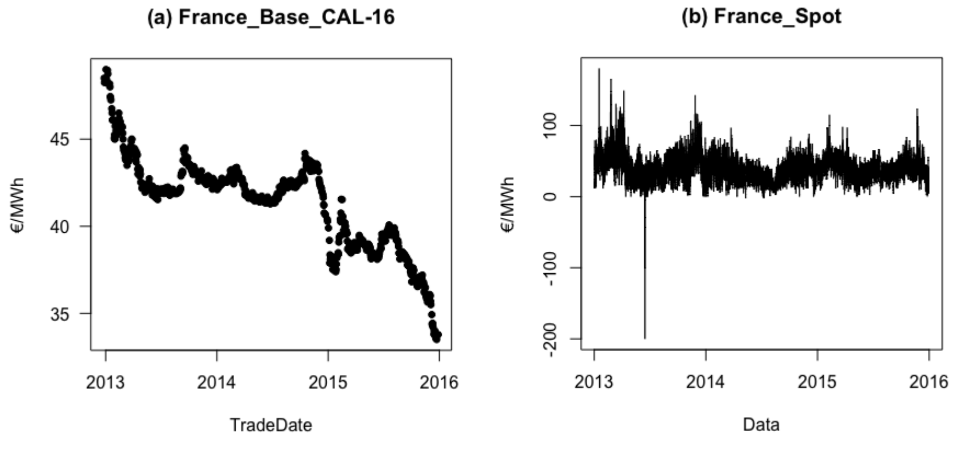

Figure 1 The left-hand side (panel a), reports the time series of future prices of the base-load yearly product CAL-16 for France. The right hand-side (panel b) the time series of hourly spot prices in France. Both in (a) and (b) the period goes from 2013 to 2016.

3. Methodology

In what follows, we shall denote with T_{start} the beginning date of the delivery period, namely, the first day of the delivery, and T_{end} the end date of a future contract with duration T_{start}^{end} . In a risk neutral world, the price of an electricity futures contract traded in *t* with delivery period from $T_{start}$to T_{end} is:

$$F_{t,T_{start}^{end}} = \frac{1}{T_{end} - T_{start}} \sum_{T=T_{start}}^{T_{end}} \mathbb{E}_t[S_T] \qquad (1)$$

Where $F_{t,T_{start}^{end}}$ is the futures price of the forward contract with delivery starting at date T_{start} and ending at date T_{end} , evaluated at time *t*; S_T is the daily average hourly day-ahead price of day *T*; $\mathbb{E}_t$ is the expected value operator conditioned to the information available at the trade time *t*. The algebraic difference between the left-hand side and the right hand side of equation 1 is the risk premium of the underlying asset:

$$RP_t^{ex-ante} = F_{t,T_{start}^{end}} - \frac{1}{T_{end} - T_{start}} \sum_{T=T_{start}}^{T_{end}} \mathbb{E}_t[S_T] \qquad (2)$$

The definition above is the so-called *ex-ante* risk premium, which is based on the specific definition of the expectations. Under a market efficiency hypothesis, expectations should coincide with realized values plus an *iid* random error term (Cartea and Villaplana, 2014; Lucia and Torró, 2011). This gives rise to the so-called *ex-post* risk premium, in which the expected values of the underlying asset is substituted with the realized values that have been observed ex-post:

$$RP_t^{ex-post} = F_{t,T_{start}^{end}} - \frac{1}{T_{end} - T_{start}} \sum_{T=T_{start}}^{T^{end}} S_T \qquad (3)$$

By using the ex-post risk premium we assume that the market is efficient and that operators' expectations are unbiased and thus the error term vanishes.

Equation (3) allows us to calculate the risk premium for each trading day *t* per each contract in our dataset. We start from hourly day-ahead (spot) time series and compute both base-load and peak load daily average prices; then, the average monthly, quarterly and yearly prices have been calculated to be used as, respectively, the *ex-post* expected monthly, quarterly and yearly day-ahead prices, each one for the corresponding contract with a given delivery period. The risk premia for each trading day *t* has then been calculated as:

$$RP_t^{j,f,k} = F_t^{j,f,k} - \bar{S}^{j,f,k} \qquad (4)$$

where $RP_t^{j,f,k}$is the risk premium at time *t*, relative to country *j* (France, Switzerland, Italy and Germany), for a contract related to a product type *k* (baseload or peak), with a specific delivery period *f* (where $f \in \mathscr{F}$, being $\mathscr{F}$ is the set of all delivery periods - that is, all monthly, quarterly and yearly deliveries for all time span considered). $F_t^{j,f,k}$ is the daily settlement future price contracted at day *t*; finally $\bar{S}^{j,f,k}$ is the mean of the daily spot prices verified in the delivery period of the contract *j* ,*f*, *k* (from now onward for brevity of notation we shall omit uppercase *j*, *f*, *k* whenever not needed).

We also construct the variable $dur_t^{j,f,k} = T_{start}(f) - t$ that measures the trading day remaining before the beginning of delivery for each contract of type *k*, country *j* and delivery period *f*. Thus,

dur_t =1 is the day before the starting of the delivery for a given future. The length of dur_t depends on the contracts, markets and types. For instance, dur_t = 246 typically denotes the beginning of exchange (nine months of commercial days before delivery) of a monthly contract.

Note that *ex-post* risk premia coincide with *ex-ante* ones under the efficient market hypothesis. To account for such an assumption, we consider the liquidity of the contract as a control. Indeed, market liquidity plays an important role in explaining the efficiency of exchanges for electricity future markets (Bevin-McCrimmon et al., 2018). The variable liq_t denotes the number of open interests open at day t-1 of each contract of type j, f, k.

A multivariate linear regression model is performed with two explanatory variables, i.e. trading days before the start of the delivery period and the futures liquidity index. This measures the average size and sign of risk premia across contracts, types and country (the intercept); it measures as well how risk premia change throughout their trading period (the beta of the dur_t variable) and the role of liquidity (the beta of the liq_t variable). The following linear regression has been estimated through OLS with robust standard errors:

$$RP_t^{j,f,k} = \beta_0^{j,g,k} + \beta_1^{j,g,k} dur_t^f + \beta_2^{j,g,k} liq_t^{j,f,k} + \varepsilon_t^{j,f,k} \tag{5}$$

where $RP_t^{j,f,k}$ is the risk premium defined in equation (4). $\beta_0^{j,g,k}$ is the intercept that depends on country j, product type k, and periods g, which are elements of the partition of the set of all delivery periods ($\mathscr{F}$) such that the periods f are grouped in monthly, quarterly and yearly. In other words, in our regression the estimation is done jointly for different values of f, provided that they identify either monthly, quarterly or yearly contracts. Consequently, $\beta_1^{j,g,k}$ is the coefficient monitoring the impact of the time to maturity, dur_t^f, which varies across delivery period f; $\beta_2^{j,g,k}$ measures the impact of market liquidity, $liq_t^{j,f,k}$, which is varying across country j (Italy, France, Germany and Switzerland), delivery period f and finally to the product type k (base-load or peak-load). Finally, $\varepsilon_t^{j,f,k}$ is an error term possibly serially correlated and/or heteroskedastic, whose variance is assumed to vary across values of g. To summarize, all coefficients vary across country j, delivery periods g, and product type k. Equation (5) defines a set of linear relationships which we jointly estimate across values of j, g, and k.

Results of Equation (5) provide a measure of the average signs and of the trends of the premia throughout all trading days, per types of contracts. Recall that the sign of the risk premia denote which size of the market is relatively more risk averse (and thus willing to pay a premium to the counterpart to fix the delivery price). We are also interested in evaluating if there is, on average, an inversion of the sign of the premia during the trading of the futures. In order to do so, we compare the average sign of the premia per each type of forward contract in each day during the first week of exchange (five days)[10] and compare it with the average value during the last week (five days) before delivery.

4. Results

As discussed before, the risk premium is caused by the hedging pressure; both consumers and retailers, due to the high volatility and unpredictability of the spot price of electricity, might want to hedge themselves from sudden price changes. Consequently, positive values of the risk premium

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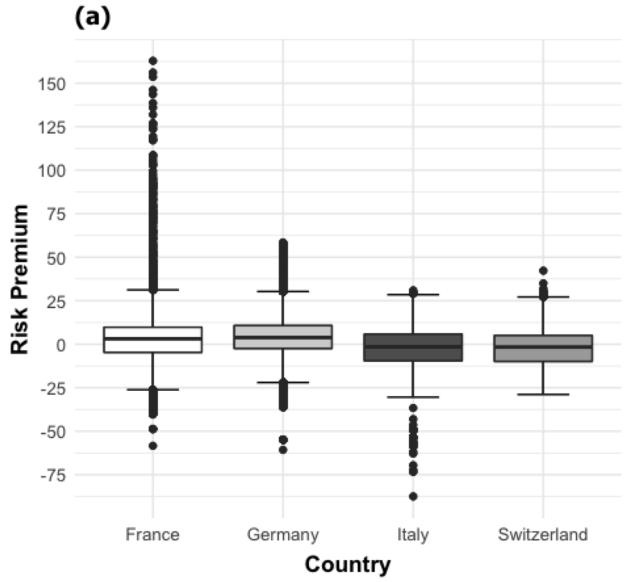
[10] We have performed the analysis also for fifteen days, and results coincide. The full table with all days is available as supplementary material.

indicate a relatively higher risk aversion of consumers; on the contrary, negative values of the premium risk indicate a situation in which producers' risk aversion is greater.

Figure 2 reports the boxplot representation of the risk premium computed on the basis of equation (3) for France, Germany, Italy and Switzerland. We notice that there is not a clear convergence of futures prices to day-ahead ones, on average, in all countries considered. Indeed, in the figure, median values are positive or negative even if near to the zero.

Observing panel (b) of Figure 2 it clear emerges that in France and Germany risk premia were negative, i.e. futures prices were higher than the average spot prices verified in the delivery period, while in Italy and Switzerland the opposite is valid. In addition, in all countries considered the risk premia for peak-load products were higher than the base-load one (except for Switzerland, in which just base-load futures were traded).

The highest risk premium volatility has been recorded in France. This was probably caused by physical characteristics of the French production system which is based mostly on electricity production from nuclear power plants. This makes prices particularly sensitive to unexpected changes of power supply, as the ones occurred at the end of 2016 when the spot price exploded from 40€/MWh to 874€/MWh (22 times higher from the starting price).[11] Indeed, the inelastic supply of this country results in spike and high volatility also in futures market that, in turn, cause higher risk premium.



(b)

	FR	DE	IT	CH
n	38981	83555	28833	8584
mean	2.61	4.41	-1.87	-2.13
sd	13.11	11.55	11.02	11.75
median	3.1	3.81	-1.54	-1.63
min	-58.39	-60.7	-87.46	-28.9
max	162.84	58.47	30.94	42.24
skew	0.76	0.26	-0.31	0.09
Excess kurtosis	7.44	1.2	0.96	-0.34

Figure 2 Risk premium boxplot (a) and average of risk premium (b).
On the left -hand side, plot (a), are represented the boxplot of risk premium for France, Germany, Italy and Switzerland with base-load and peak-load products distinction. Boxplots are graphical representation of risk premiums' distribution. The line inside box is the median. The interquartile range box represents the 50% of data. The two whiskers, on both box sides, represent the ranges for the bottom 25% and the top 25% of the data values, excluding outliers. The outliers are identify by points. On the right-hand side, table (b), presents the descriptive statistics of risk premia for each of country considered. Note that Italy and Switzerland showed negative risk premium on average (futures prices higher than spot prices); on the contrary France and Germany had on average positive risk premium.

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[11] This exceptional spike was the consequence of a unexpected outages in 2016 of about half of the French nuclear power plants, which turned France in a net power importer for three months (being normally a net exporting Country) and that induced power prices to spike up to 800 €/MWh for three times. The plot of French spot time series is available as supplementary material.

The results of the estimation of the regression model presented in Equation (4) are displayed in Table 2. The dependent variable is the daily risk premium. Robust standard errors are reported in parenthesis. The intercept measures the average value of the risk premia per each type, country and product. In France we observe that the value increases as delivery period rises, both for base-load and peak-load contract. The opposite occurs in Germany in which shorter maturity are associated with higher risk premia. For Italy and Switzerland, the highest values of risk premia are associated to quarterly products. There are negative premia for yearly Germany products, yearly peak-load products and Switzerland base-load products.

		FR		DE		IT		CH	
		Base	**Peak**	**Base**	**Peak**	**Base**	**Peak**	**Base**	**Peak**
β_0	**Monthly**	2.446 *** (0.305)	1.291 ** (0.546)	2.553 *** (0.144)	2.538 *** (0.181)	2.164 *** (0.286)	-1.646 *** (0.373)	1.116 *** (0.318)	- -
	Quarterly	10.386 *** (0.283)	6.330 *** (0.432)	1.336 *** (0.192)	0.729 *** (0.237)	3.336 *** (0.313)	2.492 *** (0.474)	4.359 *** (0.498)	- -
	Yearly	10.576 *** (0.351)	10.164 *** (0.475)	-1.039 *** (0.346)	-7.949 *** (0.584)	3.051 *** (0.634)	-0.419 (0.806)	-11.399 *** (0.389)	- -
β_1	**Monthly**	-0.002 (0.005)	0.079 *** (0.012)	-0.009 *** (0.002)	-0.005 ** (0.002)	-0.044 *** (0.004)	0.026 *** (0.008)	-0.064 *** (0.008)	- -
	Quarterly	-0.046 *** (0.001)	-0.017 *** (0.002)	0.004 *** (0.001)	0.014 *** (0.001)	-0.034 *** (0.001)	-0.031 *** (0.002)	-0.049 *** (0.003)	- -
	Yearly	-0.018 *** (0.001)	-0.012 *** (0.001)	0.014 *** (0.0004)	0.026 *** (0.001)	-0.029 *** (0.002)	-0.031 *** (0.003)	-0.022 *** (0.001)	- -
β_2	**Monthly**	0.0001 *** (0.00002)	0.003 *** (0.0003)	0.00000 (0.00000)	-0.0001 *** (0.00002)	0.00000 (0.00001)	0.001 *** (0.0001)	0.007 *** (0.001)	- -
	Quarterly	-0.001 *** (0.00002)	-0.001 *** (0.0003)	0.00002 *** (0.00000)	0.0002 *** (0.00003)	-0.0001 *** (0.00001)	-0.001 ** (0.0003)	-0.004 *** (0.001)	- -
	Yearly	-0.002 *** (0.00004)	-0.011 *** (0.001)	0.00000 (0.00001)	0.002 *** (0.0001)	-0.0003 *** (0.00005)	0.004 *** (0.001)	0.038 *** (0.001)	- -
R2	***Monthly***	*0.006*	*0.014*	*0.003*	*0.001*	*0.022*	*0.023*	*0.097*	-
	Quarterly	*0.149*	*0.007*	*0.003*	*0.021*	*0.102*	*0.037*	*0.076*	-
	Yearly	*0.227*	*0.054*	*0.172*	*0.237*	*0.155*	*0.167*	*0.528*	-

Table 2. Relationship between daily risk premium, days before the delivery and open interest.
The table provide OLS regression estimates using Eq. (12). The dependent variable is daily risk premium. Robust standard errors are reported in parenthesis. Coefficients with p-values lower than 1%, 5% or 10% are highlighted with one (*), two (**) and three (***) asterisks, respectively. R2 is the determination coefficient.

The values of the coefficients associated with the time before the delivery, β_1, show how premium change, on average, as the delivery moves away. For almost all base-load products we observe a negative coefficient, the only exception being the German quarterly and yearly contracts. This means that, as dur_t reduces, the value of the premia tends to increase; as trading time approaches the delivery period, risk premia rise. A similar tendency occurs for peak load contracts, with the notable exceptions of monthly contracts, for which risk premia reduces as maturity approaches in France and Italy, while there is no significant difference between forward and spot prices for monthly German ones.

Moreover, even if coefficients of liquidity are on average significant, they are very small, and no clear indication arises with respect to their sign as they are near to zero and displays no homogeneous sign. Finally, if we focus on the coefficients of determination, we observe some heterogeneity across countries and delivery lengths. Overall, we observe that the largest values of R-squared are observed for yearly deliveries.

In Table 3 and Table 4 we report the average signs of the premia for the first five trading days and the last five trading days before delivery., respectively It should be noted that for the majority of products the magnitude of premia tends to rise as delivery approaches (the only exception being the yearly French and German contracts). In addition, the risk premia are higher for products with longer delivery periods. Note that in Germany and France the risk premium is positive both at the begging and at the end of the trading period. On the contrary, for Italy and Switzerland, there is, on average, also a sign inversion: while at the begging of the trading period the sign is negative, it becomes positive as the delivery period approach (for Switzerland, this occurs for all products but monthly ones).

The first 5 trading days

		FR		DE		IT		CH
		Base	**Peak**	**Base**	**Peak**	**Base**	**Peak**	**Base**
t = 1	**Monthly**	0.874	5.639	1.903	3.481	*-3.485*	*-3.604*	2.359
	Quarterly	0.115	2.767	3.086	6.152	*-3.583*	*-11.019*	*-2.963*
	Yearly	6.138	10.088	21.602	32.146	*-2.214*	*-6.987*	*-14.556*
t = 2	**Monthly**	1.903	5.535	1.862	3.782	*-2.26*	0.425	2.559
	Quarterly	0.112	2.787	2.931	5.971	*-3.651*	*-8.712*	*-3.27*
	Yearly	5.745	9.879	20.977	32.854	*-2.036*	*-7.425*	*-14.464*
t = 3	**Monthly**	1.934	5.74	1.906	3.721	*-2.324*	0.561	2.357
	Quarterly	0.022	2.655	2.878	5.845	*-3.76*	*-6.777*	*-3.201*
	Yearly	5.498	9.478	20.105	32.194	*-2.048*	*-7.659*	*-14.549*
t = 4	**Monthly**	1.95	5.625	2.031	3.655	*-2.229*	0.43	2.232
	Quarterly	0.037	2.256	2.849	5.901	*-3.79*	*-6.785*	*-3.481*
	Yearly	4.984	9.122	20.149	32.022	*-2.092*	*-7.601*	*-14.694*
t = 5	**Monthly**	2.705	5.606	1.987	3.678	*-2.111*	0.526	2.053
	Quarterly	0.02	2.29	2.781	5.706	*-3.712*	*-6.649*	*-3.611*
	Yearly	4.986	9.201	19.951	31.531	*-2.168*	*-7.411*	*-14.549*

Table 3. Average of risk premium for each of the first 5 days of trading period.
The table provide average of risk premium for France, Germany, Italy and Switzerland both for base-load and peak-load products for each of the first 5 days of the trading period. Shaded cells denote negative figures.

The last 5 trading days

		FR		DE		IT		CH
		Base	Peak	Base	Peak	Base	Peak	Base
t = 1	Monthly	2,103	3,143	1,103	1,021	0,11	*-0,021*	1,222
	Quarterly	2,415	3,794	2,029	2,385	0,477	0,833	0,88
	Yearly	3,144	5,628	3,704	4,94	0,37	0,707	1,426
t = 2	Monthly	1,927	3,018	1,307	1,132	0,168	0,032	1,155
	Quarterly	2,439	3,818	2,06	2,461	0,486	0,8	1,076
	Yearly	3,289	5,751	3,842	5,063	0,432	0,913	1,654
t = 3	Monthly	1,758	2,864	1,346	1,228	0,058	*-0,087*	1,012
	Quarterly	2,478	3,783	2,151	2,487	0,646	0,924	1,219
	Yearly	3,194	5,625	3,819	5,027	0,416	1,125	1,494
t = 4	Monthly	1,744	2,792	1,327	1,233	0,031	*-0,036*	1,136
	Quarterly	2,391	3,578	2,133	2,566	0,57	0,912	1,058
	Yearly	3,198	5,798	3,926	5,163	0,446	1,055	1,659
t = 5	Monthly	1,768	2,993	1,422	1,336	0,138	0,105	1,342
	Quarterly	2,259	3,576	2,109	2,514	0,61	0,815	1,101
	Yearly	2,951	5,633	3,597	4,879	0,092	0,729	1,439

Table 4. Average of risk premium for each of the last 15 days of trading period.
The table provide average of risk premium for France, Germany, Italy and Switzerland both for base-load and peak-load products for each of the last 5 days of the trading period. Shaded cells denote negative figures.

Conclusions

In this paper we examine the relationship between day-ahead and futures prices in electricity market of Germany, France, Italy and Switzerland. The electricity futures prices depend both on the spot price expectations and on a risk component, that could be positive or negative. A positive (or negative) premium risk corresponds to a futures price higher (or lower) than the average spot price recorded during the delivery period. This signals that buyers (sellers) are willing to buy at a premium in order to fix the electricity price for the delivery period.

We analyze a large sample of data of short, medium and long-term futures contracts which spans over a decade for four big European Continental markets, namely, Italy, Germany, France and Switzerland. Our results confirm that there is no-convergence on average of future prices to the realized prices. Moreover, we show that there is on average a negative relation between risk premia and days before the delivery period: the closer the trading day is to the expiration date, the bigger the risk premium. For all countries and products considered the risk premium verified at the end of the trading period is positive. However, for Italy and Switzerland there is an inversion of the sign of the risk premia: at the begging of the trading period on average risk premium are negative, rising as expiration time approaches.

The inversion of sign might be due to market power of the participants, as conjectured in the literature by Kolos and Ronn (2008), and in paticular by the fact that power producers have a relatively weaker market power for longer maturities. Thus, power producers, in order to be sure to sell electricity in the long run, could be willing to accept a discounted price compared to the expected spot ones well ahead of the delivery. In this case, our analysis would signal that such a behavior occurs in Italy and Switzerland, but not in France and Germany, where the sign of risk premium is on average positive, both at the beginning and at the end of the trading period. Another possible reason might be related to the progressive introduction of renewables in the grid, that increased (in particular in Italy) during the period considered in the analysis, which has generated a rise in day-ahead variance (Ketterer, 2014; Maciejowska, 2020; Rai and Nunn 2020).

In any case, the detailed identification of the factors behind the risk premiums trend over time goes beyond the scope of this paper and requires further analysis to precisely identify the real causes. Further study could relate the energy production and renewables of each country to the risk premium trends that we have analyzed here.

Overall, we shown that premia have a complex facet. Their amount and trend depend on the characteristics of the products, the reference market, as well as the duration of the contract and how early they are traded compared to the delivery. This results could be of interest for market participants and traders, for both speculative and hedging perspectives, as well as monitoring agencies that could investigate further the nature of the different premia observed.

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