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The Paris Agreement and electricity markets outside the EU

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ABSTRACT

Climate change has been at the center of economic and social discussion for some years. The passage of time has intensified this debate and reflection. A well-known relevant event in this domain was the signature of the Paris Agreement in 2014, and its subsequent enforcement by European Union (EU) member countries.

This study examines if the climate change measures adopted by the Agreement had an impact on the electricity sector outside the EU28, seeking to assess whether there is international diversity in these markets or if they work uniformly at global level.

The goal of this work is to study the behavior of spot electricity prices before and after the Agreement was signed by EU members, analyze its effect in terms of spot prices, and determine the conditions that lead to stability and non-stability. We examine the behavior of spot electricity prices in two different electricity markets: the US and Brazil.

The study applies both qualitative methodologies, namely fsQCA, and quantitative methodology, in order to identify changes in the pattern of electricity price behavior with the advent of the Agreement.

Arguably, regulatory theory still incorporates the effects of the emergence of global dynamics in the regulation process. However, what this article suggests is that changes in regulatory frameworks with global impact, even if exogenous to a specific market, can profoundly alter the dynamics of that market.

KEY WORDS: electricity markets, spot price, Paris Agreement, fsQCA

JEL Classification: F68, G18, K32, P28, P48, Q43, Q58

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1. Introduction

Climate change has been at the center of economic and social discussion for some years. The passage of time has intensified this debate and reflection. A well-known relevant event in this domain was the signature of the Paris Agreement in 2014, and its subsequent enforcement by European Union (EU) member countries. Previous work (Estevão & Raposo, 2018) identifies the impact of the signature of the Paris Agreement by EU countries in 2014 in the Iberian electricity market MIBEL. This Agreement brought more stability to the spot price in MIBEL market, a reduction of volatility in the two markets and a larger number of paths that are associated with price stability.

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This study examines if the climate change measures expected after the signing of the Agreement had an impact on different markets in the electricity sector outside the EU28, seeking to assess whether there is international diversity in these markets or if they work uniformly at global level. The goal of this work is to study the behavior of spot electricity prices before and after the Agreement was signed by EU members, and to analyze its impact. We propose to examine the behavior of spot electricity prices in two different electricity markets.

In particular, we examine the Pennsylvania, Maryland and New Jersey market (PJM) and the Brazilian market (Bra), having chosen these two markets because they are from a continent different than Europe, and because one of them is the largest developed country in the world while the other is one of the largest emerging economies in the world. By doing so, we want to test if the legislation had an impact beyond the countries where it was imposed. The globalization of the markets is present in the negotiations of the same futures contracts in different parts of the globe at the same time (Scholte, 2008). For that reason, it is expectable that an important measure could influence other markets besides those of the countries that directly sign the Agreements, as happened with the study of Estevão and Raposo (2018) were the volatility decreased, but having more configurations for stability of the spot prices. For that reason, similar results are expected for these two American countries.

The study applies both qualitative methodologies, namely fsQCA, and quantitative methodology in order to identify changes in the pattern of electricity price behavior with the advent of the Agreement. The econometric approach aims to model the behavior of spot prices before and after the Agreement and the qualitative approach seeks to show the configurations that lead to the presence of stability in the spot price of electricity. We use daily data collected from several markets for a period of 6 years – 3 years prior to the Paris Agreement being signed, and 3 years after.

This paper is organized as follows: section 2 presents a brief survey of the literature, section 3 presents the traditional time-series quantitative methodology results. In section 4 the qualitative analysis fsQCA is presented and section 5 discusses the results. Finally, section 6 concludes.

2. Literature review: electricity prices behavior

Electricity markets have three main distinctive features: limited possibility of transmission, seasonality, and impossibility of storage (Janczura, Trück, Weron, & Wolff, 2013; Pietz, 2009; Pirrong & Jermakyan, 2008). Weron and Misiorek (2008) add that electricity is also a special commodity since demand depends on the weather and on the business cycle, but in the sort-term the elasticity is very reduced (Redl, Haas, Huber, & Böhm, 2009). Hence, these commodities present high volatility, and peaks in prices (Janczura & Weron, 2010), features that can be harmful to consumers (Newbery, 1998). The impossibility of storage makes electricity prices more volatile than other commodities, such as oil, gas or coal, due to the need for immediate consumption (Shawky, Marathe, & Barrett, 2003).

The Paris Agreement addresses the concerns of the world community regarding climate change "Recognizing the need for an effective and progressive response to the urgent threat of climate change" (United Nations, 2015, p. 1). Large externalities are associated with the production and the consumption of energy often in the form of emissions of greenhouse gases (Jacobsen, 2015). The European Council (2014) defined three main objectives in this field: growth of renewable energy to a minimum of 27% of the energy consumption, target of 40% in greenhouse gas emissions relative to 1990 levels, and energy efficiency through possible modifications to the energy efficiency directive. In view of the imposition of these measures it is to be expected that spot prices will increase because the cost of producing renewable energy is higher than the cost of producing fossil fuels, and also market instability, due to a change of legislation. The Paris Agreement does not clearly mention fossil fuels, but it is implicit that there is a strong commitment towards a low-carbon energy shift, providing arguments to increase the speed for fossil fuel subsidies reform (Rentschler & Bazilian, 2017). Climate change affects consumer behavior and consequently the consumption and price of electricity (Véliz, Kaufmann, Cleveland, & Stoner, 2017). In addition, modern electrical power systems face the inherent uncertainty and variability of renewable energy resources (Chakraborty, Baeyens, & Khargonekar, 2018). Paraschiv, Erni, & Pietsch (2014) brought to scrutiny the formation of prices in the German market from renewable energies photovoltaic and wind. Ketterer (2014) and Cardella, Ewing, & Williams (2017) emphasize the significance of this kind of research given the increasing production of renewable energy in recent years. Still, guaranties given to producers of energy from renewable sources affects the prices to the final consumer (Ketterer, 2014).

Nevertheless, additional analyse is required in this area, not only the necessity of subsidies in the carbon price, but also factors like surplus of generation or solid energy efficiency (International Energy Agency, 2016). In developed and developing countries, many electricity systems are not completely liberalized, "so the textbook model in which the carbon price is passed through to marginal electricity prices, driving dispatch decisions, does not directly apply" (International Energy Agency, 2016, p. 48).

The introdution of open markets for electricity and the liberalization of the power industry has split activities into generation, transmission and distribuion. Policy makers have the goal of reducing the volatility because they see it as a risk to economies and wish to avoid energy price shocks (Atalla, Blazquez, Hunt, & Manzano, 2017). One of the goals of deregulation is to bring competition between generation units to deliver consistent electricity supply to consumers. The liberalization of energy markets brought about a switch from coal to natural gas, but with increased macroeconomic volatility (Atalla et al., 2017), with the Scandinavian market and the German market being the main electricity markets in Europe.

Gummer et al. (2017) show that electricity prices increase 61% between 2004 and 2016 in the UK, and defends the main causes of the increase is a rise in wholesale and network costs, and the impact of the climate policies. Similar results are obtained in Australia where the retail electricity prices also increased between 2006 and 2013 but the increase almost stagnated (Climate Change Authority, 2016). The report of the Committee on Climate Change by Gummer et al. (2017) estimates a growth in electricity prices of 33% between 2016 and 2030, due to climate policy costs and the increase of network costs and wholesale. In the same direction, the study (International Energy Agency, 2016) predicts that as the production of energy through fossil fuels decreases, this will be directly reflected in a reduction of carbon prices on electricity. If consumption of reweable energy is expected to increase, importance must be given to the plants already in place because following Ziegler, Gonzalez, Rubert, Smolka, and Melero (2018, p. 1261) "in 2016, 12% of the installed wind turbine capacity in Europe was older than 15 years. This share increases to 28% by 2020".

Estevão & Raposo (2018) provided evidence of lower volatility and higher price stability – in terms of a larger number of configurations leading to stability – in Portugal and Spain after the introduction of the Paris Agreement in 2014. It is an open question if other markets reacted in a similar fashion. This study provides evidence from two very different markets: Brazil and the PJM US energy market. The current study has the goal of assessing supposing both markets reacted similarly to the Paris Agreement. It is expected that the markets have the same behavior because, being liberalized, the different types of agents can take positions on this commodity, regardless of where they are from and of the type of development that the country has.

To measure the reaction of these markets, we adopt a mixed-methodologies approach: a quantitative approach to identify the time series model that better describes the behavior of spot prices, i.e., determine how prices have been behaving, and not determine which factors (variables) lead to price formation and validate the presence of price peaks, and a qualitative fsQCA approach to find the paths to stability and non-stability in these markets, i.e., which variables are important to achieve stability of spot electricity prices.

3. Time series econometric method

Financial markets are characterized by higher volatility and, for that reason (Wooldridge, 2006; 2013), spot electricity prices are extremely more volatile than any other commodities' (Girish, Rath, & Akram, 2018).

3.1 Sample description

To analyze the existence of stability in spot electricity prices in the PJM and Brazilian markets, we collect data from Datastream for the day after market (spot price) for the period between October 24, 2011 and October 24, 2017. From now on, the term spot price refers to the electricity price for next day delivery.

The sample is divided in two sub samples, the first one the data are between October 24, 2011 and October 24, 2014 (the date of signature of the Paris Agreement), and the second is the period after the signature. The first period has 785 observations and the second

Table 1. Summary Statistics

PJM before 10/24/2014		Bra before 10/24/2014	
Mean	31.88894	Mean	112.0846
Standard Error	0.893534	Standard Error	2.63879
Median	27.11	Median	90.55
Mode	27.78	Mode	27.51
Standard Deviation	25.03491	Standard Deviation	73.93322
Sample Variance	626.7469	Sample Variance	5466.121
Kurtosis	160.9855	Kurtosis	-0.59126
Skewness	10.32071	Skewness	0.798545
Range	481.41	Range	253.04
Minimum	15.32	Minimum	17.19
Maximum	496.73	Maximum	270.23
Sum	25032.82	Sum	87986.4
Count	785	Count	785
PJM after 10/24/2014		**Bra after 10/24/2014**	
Mean	27.24383	Mean	71.5873
Standard Error	0.362403	Standard Error	1.957379
Median	25.86	Median	53.875
Mode	19.73	Mode	36.12
Standard Deviation	10.14727	Standard Deviation	54.80661
Sample Variance	102.9671	Sample Variance	3003.764
Kurtosis	39.70085	Kurtosis	2.075204
Skewness	4.688827	Skewness	1.354166
Range	140.77	Range	248.56
Minimum	2.33	Minimum	8.09
Maximum	143.1	Maximum	256.65
Sum	21359.16	Sum	56124.45
Count	784	Count	784

period has 784 observations. Data are for the 5 days of the working week. The unit of measure in the spot price contracts is euros for a megawatt per hour (€/Mwh). Each contract guarantees the supply of one Mwh of electricity. Table 1 presents the summary statistics for the data.

Table 2. Summary models

	R^2	Standard deviation	Volatility market	Type Model	Average
Brazil before	0.016583	73.88€/Mwh	151%	GARCH (1,1)	MA(1) MA(15) MA(23)
Brazil after	0.099424	73.88€/Mwh	102%	GARCH (1,1)	AR(1) AR(2) AR(3) MA(1)
PJM before	0.131543	25.02€/Mwh	431%	GARCH (1,1)	AR(1) MA(1) MA(2)
PJM after	0.252881	10.14€/Mwh	469%	GARCH (1,1)	AR(1) MA(1)

3.2. Results for the econometric method

The descriptive statistics show that in the PJM market before 2014, spot price has a standard deviation of 25.02€/Mwh and the mean of price is 31.92€/Mwh, with the minimum price of 15.32€/Mwh and a maximum spot price of 496.73€/Mwh. In the case of Brazil, the average spot price was 112.48€/Mwh with a standard deviation of 74.21€/Mwh. The maximum value of electricity was 270.23€/Mwh and the minimum 17.19€/Mwh.

After the Agreement, the descriptive statistics reveal a decrease of the mean price to 27.27€/Mwh and a standard deviation of 10.14€/Mwh with the maximum and minimum prices decreasing to 134.10€/Mwh and 2.33€/Mwh. In turn, the Brazilian market after the Agreement, presented an average price of 71.58€/Mwh (decrease) with a decrease of the maximum of the spot price to 256.65€/Mwh and also a decrease of the minimum to 8.09€/Mwh

The PJM market before the Paris Agreement is defined by a GARCH model (1,1) where the volatility is according to AR(1) MA(1) MA(2). After the Agreement, in this market, the better model to describe the spot price is GARCH (1,1). The model also explains the errors, and the mean behaves according to AR(1), MA(1).

The same exercise was performed for the Brazilian market. Results before the Paris Agreement confirm that the GARCH model (1,1) better describes the volatility where the mean behaves according to MA(1) MA(15) MA(23). After 2014, in the Latin American country the GARCH(1,1) model also explains the errors, and the mean behaves according to AR(1) AR(2) AR(3) MA(1). (Table 2)

Following Bierbrauer, Trück, and Weron (2004), who define a price peak when the volatility is higher than 30% of the mean, there are several cases when this happens, with the consequence of large annual volatility in both markets, but, in particular, in PJM with volatility around 430% before, and 470% after the Agreement. In Brazil the existence of price peaks is less noted, with volatility near to 150% and 100%, respectively, before and after 2014.

4. Qualitative comparative analysis method

With the goal of analyzing which conditions lead to lower volatility in the spot price of electricity (i.e., conditions for stability in electricity prices) we use the qualitative methodology qualitative fuzzy-set QCA. We interpret a possible increase in the number of paths that lead to stability as a signal of more stability in the market.

The fsQCA analysis requires that the cases be scaled into significant clusters that reflect the degree of price stability. The degree ranges from one (price stability) to zero (absence of price stability). A score of 0.5 refers to the crossover point (Ragin, 2008a). Following the rationale of Bierbrauer et al. (2004), stability in electricity spot prices is assumed to correspond to situations in which prices are within a 30% variation of the mean for the observed period. For the crossover point, an area of 30% is divided into two bands of 15% (one above and one below the central band of stability). The remaining area corresponds to the values of instability, that is, the two bands farther away from the mean, 15% each, such as in Estevão & Raposo (2018). Table 3 summarizes the statistics and calibration values of the outcomes and antecedent conditions.

Table 3. Descriptive statistics and calibration values of the outcomes and antecedent conditions

	Descriptive statistics				Calibration		
Outcomes and Conditions	Mean	Std dev	Max	Min	Stability	Ambiguity	Absence of stability
Spot PJM before	31.92	25.02	496.73	15.32	]27.30 ; 36.67[	]24.11, 27.73[U]36.67 , 42.17[	< 24.11 U > 42.17
Spot Bra before	112.49	74.22	270.23	17.19	]97.46 ; 128.89[	]84.75 , 97.46[U]128.89 , 148.22[	< 84.75 U > 148.22
Spot PJM after	27.28	10.15	143.10	2.33	]23.71 ; 31.36[	]20.62 , 23.71[U]31.36 , 36.06[	< 20.62 U > 36.06
Spot Bra after	71.58	54.91	256.65	8.09	]62.27 ; 82.35[	]54.15 , 62.27[U]82.35 , 94.70[	< 54.15 U > 94.70
dax before	8,001.70	1,252.45	10,029.43	5428.11		(9760; 7950; 6000)*	
dax after	10,982.57	1,047.12	13,043.03	8,752.87		(12700; 10800; 9450)*	
oil before	78.74	3.72	89.34	72.37		(86; 78; 73.5)*	
oil after	45.02	8.25	74.22	28.10		(60; 43; 29)*	
nordpool before	34.50	9.01	96.13	7.94		(48; 34; 24)*	
nordpool after	26.55	7.24	81.67	6.31		(37.5; 27; 12)*	
eex before	42.46	9.85	98.98	8.40		(58; 42; 28)*	
eex after	34.46	9.43	101.92	1.52		(49.5; 33.5; 21.5)*	
gas before	2.70	0.60	5.84	1.38		(3.45; 2.7; 1.73)*	
gas after	2.44	0.44	3.56	1.35		(3.2; 2.5; 1.6)*	
sre before	15.00	11.00	40.23	3.23		(35.6; 10; 3.8)*	
sre after	58.76	15.22	84.31	25.46		(82; 60.5; 31)*	
coal before	64.85	9.19	84.18	52.79		(80; 63.5; 53)*	
coal after	59.56	11.99	83.05	44.48		(81; 56; 46)*	

*Cuts: 95%; 50% and 5%

Label: Max=maximum; Min = minimum; Std dev = standard deviation; (dax) daily DAX index, (oil) average price of oil barrel in euros, (nordpool) average price of electricity in the Scandinavian market, (eex) electricty price in the German market/ Megawatt Hour, (gas) natural gas price - per Million British Thermal Units, (sre) renewable energies index - Total Market Renewable Energy Equipment, (coal) average spot price of coal in euros per metric ton

The advantages of the fsQCA methodology, in comparison to other methodologies, is providing a better understanding of the conditions to achieve the stability in spot price, in an application in finance similar to what has been performed in different contexts (Wu, Yeh, Huan, & Woodside, 2014). Another advantage of this methodology is the fact the usual problems of correlation of variables in a regression technique (multicollinearity) are not of concern here – it is one of the assumptions of the fsQCA (Rihoux & Ragin, 2009).

4.1 Sample description

We use the same data as in the previous section where the econometric methodology results were discussed. For the application of fsQCA, we choose a set of conditions that are important to explain the electricity price behavior in these two markets. We use the daily DAX index (variable dax), which is the main reference European stock market index (Oberndorfer, 2009), to consider the relation between electricity prices and other forms of investments. The average spot price of electricity in the Scandinavian market (variable nordpool) and the electricity price in the German market per Mwh (variable eex), the most important electric markets in Europe (European Commission, 2016), are also included. The most important energy sources for the production of electricity, oil, coal and gas, are also included – the price of a barrel of oil in euros (variable oil), price of coal in euros per metric tonne (variable coal) and the price of natural gas per million BTUs (variable gas) (Paraschiv et al., 2014). We also consider the renewable energies index—Total Market Renewable Energy Equipment (variable sre).

4.2 Analysis of the necessary condition

We test the markets of Pennsylvania, New Jersey and Maryland (PJM) and Brazil (Bra) and the variables dax, oil, nordpool, eex, gas, sre and coal to assess if necessary conditions exist for the outcome in the sub periods before and after the Paris Agreement. Usually, a condition or a combination of configurations is necessary if the consistency score exceeds 0.8 (Ragin, 2000; Ragin, 2008a; Schneider, Schulze-Bentrop, & Paunescu, 2010). Based in (Ragin, 2008b), you define the cut of necessary conditions in 0.8. The output shows that for the PJM market before the Agreement, there exists only one condition necessary for stability in this market (in this case, stability in gas prices); and after the Agreement there is still one condition for the stability in spot electricity prices, this time oil. The same procedure was followed for non-stability and no necessary conditions were found (table 4).

The same analysis was conducted for the Brazilian market and the results are different. In the case of the necessary conditions for stability, before October 2014, three conditions exist, dax, gas and non-coal; whereas after the Agreement, oil is the sole necessary condition. Examining the necessary conditions for non-stability in this market we find that before the Agreement there are two conditions (variables coal and non-dax.); and after the Agreement, there are no necessary conditions for the non-stability in the spot prices in the Brazilian market.

4.3. Analysis of the sufficient conditions sets

After the study of necessary conditions, the next procedure is to analyze the sufficient conditions. For that, following the recommendations of (Ragin, 2008b) for a large sample, we accept a minimum of 4 observations of configurations that lead to stability or non-stability of the spot prices in these markets. Following (Ragin, 2008a), (Woodside, Prentice, & Larsen, 2015), we adjust the cut-values depending on the number of items in each variable and its statistics.

Based on the table 5, the results show that the PJM market has two configurations for stability in spot prices, with a coverage solution of 0.38 and a solution consistency of 0.90. In the Brazilian case, there are more configurations (five) for the period before the Agreement, with a solution consistency of 0.88 and a coverage solution of 0.71. After the Agreement (table 6), the North American market presents two different configurations and the Latin American market has only one configuration, and respectively, presented a solution coverage of 0.31 and a solution consistency of 0.86 in the first case, whereas in the second case, 0.32 and 0.94 in terms of coverage and consistency.

In both cases – PJM and Brazilian markets, and also before and after the Agreement – the individual and overall consistency are higher than 0.8. In terms of coverage, the recommendations of (Fiss, 2011; Ragin, 2008b; Woodside, 2013) is more than 0.25 and the results, individual and overall, are aligned. For example, in the configurations number 2 of PJM market, the individual consistency is 0.89. Such score means that in 89 per cent of cases where this configuration of conditions is present stability occurs. The coverage level of the causal configuration number 2 is 0.28. Such score means that 28 per cent of stability occurrences took place precisely due to this configuration.

In the table 7, for the PJM market, before 2014, following the recommendations of (Prentice & Woodside, 2013) for the analysis of the negation conditions, there are three sufficient condition for non-stability.

Table 4. Results of analysis of the necessary conditions

Analysis of Necessary Conditions																
Outcome variable	fsPJM before		~fsPJM before		fsBrasil before		~fsBrasil before		fsPJM after		~fsPJM after		fsBrasil after		~fsBrasil after	
Conditions tested	Consis-tency	Cover-age	Consis-tency	Cover-age	Consis-tency	Cover-age	Consis-tency	Cover-age	Consis-tency	Cover-age	Consis-tency	Cover-age	Consis-tency	Cover-age	Consis-tency	Cover-age
fsdax	0.743028	0.630377	0.596012	0.644610	0.862688	0.801068	0.480808	0.481460	0.726511	0.523978	0.612734	0.756774	0.782916	0.733479	0.541267	0.551793
~fsdax	0.581100	0.530148	0.658242	0.765560	0.441573	0.440929	0.801336	0.862888	0.662759	0.499842	0.614580	0.793739	0.521582	0.510975	0.738564	0.787332
fsoil	0.617744	0.552550	0.702888	0.801488	0.574334	0.562275	0.712295	0.751998	0.835916	0.563528	0.669288	0.772660	0.881594	0.772009	0.600295	0.572019
~fsoil	0.778065	0.672585	0.607593	0.669563	0.746676	0.706456	0.585383	0.597263	0.662770	0.539230	0.621921	0.866500	0.511269	0.540333	0.760741	0.874865
fsnordpool	0.648723	0.588790	0.665208	0.769672	0.623959	0.619837	0.639520	0.685092	0.767142	0.554801	0.639128	0.791537	0.712574	0.669410	0.610397	0.623974
~fsnordpool	0.746227	0.636156	0.644601	0.700537	0.682999	0.637284	0.645125	0.649128	0.711752	0.535259	0.640523	0.824884	0.599727	0.585855	0.676605	0.719224
fseex	0.643432	0.569698	0.658128	0.742848	0.532169	0.515718	0.724086	0.756704	0.774203	0.578571	0.599221	0.766852	0.721282	0.700177	0.593441	0.626863
~fseex	0.709566	0.619498	0.618774	0.688693	0.748943	0.715676	0.536593	0.552950	0.688017	0.500617	0.670692	0.835705	0.615614	0.581857	0.716162	0.736565
fsgas	0.820178	0.694099	0.593212	0.639986	0.851956	0.789135	0.504888	0.504315	0.797046	0.600269	0.596359	0.769117	0.769955	0.753232	0.556020	0.591897
~fsgas	0.574590	0.525617	0.716456	0.835504	0.464853	0.465423	0.788894	0.851774	0.693429	0.500796	0.690055	0.853425	0.582834	0.546770	0.768190	0.784190
fssre	0.676903	0.628264	0.550622	0.651504	0.727857	0.739406	0.449447	0.492366	0.645420	0.472617	0.650817	0.816109	0.591768	0.562884	0.684617	0.708611
~fssre	0.624525	0.521568	0.685825	0.730167	0.500295	0.457308	0.762121	0.751241	0.748873	0.556024	0.579430	0.736731	0.693658	0.669008	0.577685	0.606275
fscoal	0.591031	0.535153	0.664974	0.767573	0.478348	0.474059	0.800608	0.855621	0.683437	0.526598	0.586075	0.773315	0.705971	0.706592	0.499756	0.544293
~fscoal	0.743304	0.635086	0.597286	0.650572	0.854313	0.798921	0.507873	0.512171	0.705802	0.498931	0.641220	0.776223	0.544693	0.500161	0.730601	0.730013

But in the Brazilian market the number of sufficient conditions found is two. In the case of non-stability, for the sufficient conditions after 2014 (table 8), the opposite is found – this means that the PJM market has just two sufficient condition and the Brazilian market has 3 sufficient conditions. The results obtained for the non-stability in both markets and periods present individual and overall consistency in agreement with (Ragin, 2008a) and (Fiss, 2011). The same results are achieved in terms of coverage (tables 7 and 8).

5. Discussion of the results

This Agreement brought to the PJM American market different configurations that lead to stability in the prices of electricity, but the number of configurations is the same as previously. The highlight is that the variables nordpool, sre and coal have the same behavior in one configuration, before and after. This means that when we are in the presence of stability in these three variables, there also exists stability in this market. It should be noted that the variables in one configuration before de Agreement, the same variables (nordpool, sre and coal) have opposite behavior in the two periods. For the Brazilian market, it is more difficulty to obtain a condition to have stability in spot prices of electricity (the number changes from 5 combinations to 1 combination), it being important to mention that, after the Agreement, variables eex and gas are no longer significant in explaining the electricity price in Brazil as before. Previous to the Agreement, the variable gas was always present in the conditions for stability in a positive way, i.e., when there was stability in the spot electricity

Table 5. Results of the intermediate solutions before the Paris Agreement (outcome: PJM and Bra)

	Intermediate solution PJM before 10/24/2014		Intermediate solution Brasil before 10/24/2014				
	Model: 2014PJM = f(oil_ before, gas_before, eex_ before, nordpool_before, dax_before, sre_before, coal_before)		Model: 2014Bra = f(oil_ before, gas_before, eex_ before, nordpool_before, dax_before, sre_before, coal_before)				
	1	2	1	2	3	4	5
fsdax_before	●	○	●	●	●	●	∘
fsoil_before	∘	●	∘	∘			•
fsnordpool_before	○	●		•	∘	•	•
fseex_before	●	○		○	○	•	○
fsgas_before	●	●	●	●	●	●	●
fssre_before	●	○	●		●	●	∘
fscoal_before	∘	●	○	○	○	○	•
Consistency	0.92	0.82	0.91	0.92	0.91	0.88	0.90
Raw coverage	0.27	0.21	0.04	0.008	0.03	0.01	0.02
Unique coverage	0.14	0.08	0.57	0.37	0.50	0.28	0.21
Overall solution consistency	0.90		0.88				
Overall solution coverage	0.38		0.71				

Label: Max=maximum; Min = minimum; Std dev = standard deviation; (dax) daily DAX index, (oil) average price of oil barrel in euros, (nordpool) average price of electricity in the Scandinavian market, (eex) electricty price in the German market/ Megawatt Hour, (gas) natural gas price - per Million British Thermal Units, (sre) renewable energies index - Total Market Renewable Energy Equipment, (coal) average spot price of coal in euros per metric tonne; full black circles (●) indicate the presence of a condition, and center white circles (o) indicate its absence. Large circles indicate core conditions; small ones, peripheral conditions. Blank spaces indicate "does not contribute to configuration".

price, the Brazilian market stability also existed in the prices of gas. After the Agreement, the variable gas is no longer necessary to explain the stability in the electricity market. It is also relevant to mention the behavior of variable coal before the Agreement: out of the 5 configurations obtained, 4 configurations have non-stability in the price of coal (has the opposite behavior). After the Agreement the variables dax, oil and coal, when they are stable, and nordpool and sre (when these are instable) are the condition for stability in the Brazilian market.

Regarding the configurations to non-stability in these markets, it is noticeable that the PJM market reduces the number of configurations from three to two. Before 2014 when we are in the presence of non-stability in the American market, in the Scandinavian market (variable nordpool) the prices are stable. In the opposite side is the case of the variable gas which has always (in the three conditions) the same behavior of non-stability. After the Agreement, for the existence of non-stability, the variables dax,

Table 6. Results of the intermediate solutions after the Paris Agreement (outcome: PJM and Bra)

	Intermediate solution PJM after 10/24/2014		**Intermediate solution Bra after 10/24/2014**
	Model: 2014PJM = f(oil_ before, gas_before, eex_ before, nordpool_before, dax_before, sre_before, coal_before)		**Model: 2014Bra = f(oil_ before, gas_before, eex_ before, nordpool_before, dax_before, sre_before, coal_before)**
	1	2	1
fsdax_after	o (small)	● (small)	● (large)
fsoil_after	● (small)	o (small)	● (large)
fsnordpool_after	● (large)	● (large)	O (large)
fseex_after	● (small)	● (small)	
fsgas_after	o (small)	● (small)	
fssre_after	O (large)	O (large)	O (large)
fscoal_after	● (large)	● (large)	● (large)
Consistency	0.86	0.89	0.94
Raw coverage	0.24	0.28	0.31
Unique coverage	0.03	0.06	0.31
Overall solution consistency	0.86		0.94
Overall solution coverage	0.31		0.32

Label: Max=maximum; Min = minimum; Std dev = standard deviation; (dax) daily DAX index, (oil) average price of oil barrel in euros, (nordpool) average price of electricity in the Scandinavian market, (eex) electricty price in the German market/ Megawatt Hour, (gas) natural gas price - per Million British Thermal Units, (sre) renewable energies index - Total Market Renewable Energy Equipment, (coal) average spot price of coal in euros per metric tonne; full black circles (●) indicate the presence of a condition, and center white circles (o) indicate its absence. Large circles indicate core conditions; small ones, peripheral conditions. Blank spaces indicate "does not contribute to configuration".

oil, nordpool, sre and coal must have stability in their prices. When the variable eex presents not stability in its prices it can lead to no stability in the market PJM. The Latin American market shows that the Agreement increases the number of configurations for the non-stability of the prices, from two to three. It is a common denominator for both periods the fact that, in order to achieve non-stability, the variable dax has non-stability. In the period before 2014, the necessary conditions sre and coal are present in both solutions as core conditions, which means that when we are in presence of stability in the prices of index of energy renewables and the prices of coal, there are indications that there may be non-stability in the prices of the Brazilian market. After the Agreement, the variable sre as necessary condition is a core conditions in the three solutions presented and we have indications of non-stability when the prices of index energy renewable are stable. In the opposite direction, dax and oil variables are negatively correlated with the Brazil-

Table 7. Results of the intermediate solutions before the Paris 2030Agreement (outcome: ~PJM and ~Bra)

	Intermediate solution ~PJM before 10/24/2014			**Intermediate solution ~Brasil before 10/24/2014**	
	Model: ~2014PJM = f(oil_ before, gas_before, eex_ before, nordpool_before, dax_before, sre_before, coal_before)			**Model: ~2014Bra = f(oil_ before, gas_before, eex_ before, nordpool_before, dax_before, sre_before, coal_before)**	
	1	2	3	1	2
fsdax_before	•	◦	◦	○	○
fsoil_before	•	•	◦		○
fsnordpool_before	●	●	●	○	•
fseex_before		○	•	●	●
fsgas_before	○	○	○	○	○
fssre_before	●	◦	●	◦	●
fscoal_before	◦	•	•	●	●
Consistency	0.95	0.96	0.95	0.98	0.99
Raw coverage	0.22	0.21	0.01	0.39	0.19
Unique coverage	0.10	0.07	0.03	0.24	0.04
Overall solution consistency		0.95		0.98	
Overall solution coverage		0.36		0.43	

Label: Max=maximum; Min = minimum; Std dev = standard deviation; (dax) daily DAX index, (oil) average price of oil barrel in euros, (nordpool) average price of electricity in the Scandinavian market, (eex) electricty price in the German market/ Megawatt Hour, (gas) natural gas price - per Million British Thermal Units, (sre) renewable energies index - Total Market Renewable Energy Equipment, (coal) average spot price of coal in euros per metric tonne; full black circles (●) indicate the presence of a condition, and center white circles (○) indicate its absence. Large circles indicate core conditions; small ones, peripheral conditions. Blank spaces indicate "does not contribute to configuration".

ian spot prices of electricity. The other variables do not have a defined pattern of behavior, varying from configuration to configuration.

In what concerns the quantitative methodology, a reduction of volatility after the Paris Agreement is identified, decreasing price peaks in both markets; the Brazilian market has a different behavior than the PJM market, which is confirmed with lower volatility. Although the Brazilian market presents lower volatility than the PJM market, it is more difficult to model the behavior of spot prices, as can be observed by the R squared of the models, that is, the model has a lower explanatory power.

6. Conclusions

Summarizing, the Paris Agreement brought to the PJM market more stability, since the volatility decreased after the signature of the Agreement, despite the number of configurations leading to stability remaining the same as before the Agreement. Analyzing conditions for non-stability, the number of configurations de-

Table 8. Results of the intermediate solutions after the Paris 2030Agreement (outcome: ~PJM and ~Bra)

	Intermediate solution ~PJM after 10/24/2014		Intermediate solution ~Bra after 10/24/2014		
	Model: ~2014PJM = f(oil_ before, gas_ before, eex_ before, nordpool_before, dax_before, sre_before, coal_before)		Model: ~2014Bra = f(oil_ before, gas_before, eex_ before, nordpool_before, dax_before, sre_before, coal_before)		
	1	2	1	2	3
fsdax_after	●	●	○	○	○
fsoil_after	●	●	◦	◦	◦
fsnordpool_after	●	○	◦	◦	•
fseex_after	○	○	◦	◦	•
fsgas_after	○	•	◦		•
fssre_after	●	●	●	●	●
fscoal_after	●	●		•	•
Consistency	0.97	0.96	0.99	0.99	0.98
Raw coverage	0.22	0.23	0.37	0.21	0.21
Unique coverage	0.03	0.04	0.17	0.008	0.05
Overall solution consistency	0.96		0.99		
Overall solution coverage	0.26		0.44		

Label: Max=maximum; Min = minimum; Std dev = standard deviation; (dax) daily DAX index, (oil) average price of oil barrel in euros, (nordpool) average price of electricity in the Scandinavian market, (eex) electricty price in the German market/ Megawatt Hour, (gas) natural gas price - per Million British Thermal Units, (sre) renewable energies index - Total Market Renewable Energy Equipment, (coal) average spot price of coal in euros per metric tonne; full black circles (●) indicate the presence of a condition, and center white circles (◦) indicate its absence. Large circles indicate core conditions; small ones, peripheral conditions. Blank spaces indicate "does not contribute to configuration".

crease from three to one, meaning that it is more difficult to have non-stability in the prices. In sum, the PJM market price stability benefited from the Agreement. These results are similar to those found by (Estevão & Raposo, 2018) for the MIBEL market.

In what concerns the Brazilian market, the situation got worse after the Agreement, in terms of price stability, when considering the number of configurations for price stability that decreased from 5 to 1. Regarding non-stability, there are more configurations after the signature of the Agreement. It will be interesting to further examine in the future which legislative initiatives or policy measures took place in this country to justify the difference in results compared to developed countries such as Spain or the US. In fact, the different results found for Brazil could be explained by some change in legislation in 2015, or can be due to the fact that it is a developing country. Future studies conducted for emerging economies like China, India or Russia can further clarify this matter.

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