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Spatial effects in the bid price setting strategies of the wholesale electricity markets: The case of Colombia

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Abstract

Weather conditions in Colombia vary greatly throughout the territory and therefore the location of electricity generating plants plays a key role in their bid pricing strategies. To account for these location-specific pricing strategies this paper estimates a Spatial Durbin Model (SDM) with monthly data gathered from the 17[th] largest hydraulic electricity generating plants of Colombia on bid prices, generation, energy inputs and positive reconciliation over the period January 2005-August 2015 and controlling also for the system marginal prices and the economy cycle. The paper reports three main results. First, firms´ bid prices are negatively affected by the energy inputs of the rivals, second they are unaffected by positive reconciliation payments to the rivals and third they are negatively affected by the generation amounts of the rivals. One potential policy recommendation of these results is the need to implement balancing markets to signal more efficiently the pricing strategies in these markets.

Key words: Bid Price, wholesale electricity market, Spatial Durbin, Colombia

JEL Classification: C23, D43, L25

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1. Introduction

Why does location matter for the bid pricing strategies of electricity generating plants in Colombia? How important is the country's physical geography in the location decisions of them? These questions are unanswered in the international literature on wholesale electricity markets price setting.

The Colombian wholesale electricity market is an interesting case to give an answer to these questions due to the specific geographical features of Colombia, the large dependence of the Colombian system on the hydraulic technology to generate electricity and the interlink between geography, climatic conditions and hydraulic technology. The physical geography of Colombia gives rise to all kinds of weather conditions making the periods of drought and/or rain to be non-homogeneous across the country. Phenomena such as "El Niño", as opposed to it is generally understood, do not have the same effects in the different Colombian regions. So, for instance it could happen that the Northern parts of the country are suffering from a period of drought whereas in the central parts the climatic conditions are just opposed. This situation would badly affect the water reservoir levels of the electricity generating units located in the North and would benefit those located in the central parts since they could impound water and play strategically with their supplies of electricity. Strategies of this kind are feasible in Colombia since the wholesale electricity market is largely dependent on hydraulic generation on the one hand and the fact that Colombian physical geography has a sizeable impact on weather conditions on the other. In a broader sense, electricity generating units not only have to be aware of variables such as domestic demand and the level of water available in their reservoirs, but they should also incorporate into their reaction functions the geographical location of the competitors. Key variables in successful price setting strategies such as power generation and water reservoir levels become dependent on how well located a plant is with respect to the rivals. Therefore the specific location of the hydraulic generating plants becomes a source of strategic behavior for their bid pricing strategies.

The use of physical geography variables has been very common within the framework of the traditional economic development theories and in the geographical economics (or New Economic Geography) literature to explain differences in levels of development between countries, differences in growth rates, the existence of spatial gradients in terms of incomes and human capital (Hall and Jones, 1999 Gallup et al. 1999, Lopez-Rodriguez et. al. 2007, Lopez-Rodriguez et. al. 2011, Bruna et al. 2016). However, the use of geographic variables is quite scarce in the analysis of the bid pricing strategies in the electricity generation markets. For instance, Burnett and Zhao (2014), estimate a spatial econometrics model to explain the wholesale electricity prices in the market of New Jersey, Pennsylvania and Meryland (PJM). They conclude that the geographical nature of the transmission system influences the forecasting of the zonal spot prices. Popova (2004), studying the same market concludes that the network topology and the market structure of PJM, is responsible for the spatial correlation presented between spot electricity prices.

Traditionally the bid pricing strategic behaviour of an electricity generation plant is analysed on account of the timing in which the energy is produced. Thus, generators consider the opportunity cost of producing today or keep their water levels for future production. In this paper we model the Colombian generators´ bid pricing strategies considering not only the dynamic problem (produce today versus produce in the future), but also the geographical location of the rivals and therefore factoring in the effects that physical geography can have on their decisions. To incorporate this double aspect (dynamic-spatial) a panel spatial Durbin model is estimated where the physical geography is incorporated in the spatial weighting matrix (usually labelled as W) of the model. With the geographic information related to the longitude and latitude of each plant of hydraulic generation, the off-diagonal elements of the matrix are calculated taking into account the inverse of the Euclidean distance between each plant. W, therefore implicitly captures the climatic specificities to which the electricity generating plants are exposed and though the matrix provides valuable information to infer the water reservoir levels and the bid pricing strategies of the rivals. The model is estimated with monthly data over the period January 2005 to December 2015. The results of the model show that the relative values (provided by the weighting matrix) on the key variables that explain the bid pricing strategies of electricity generating plants are more important than the absolute ones. These results inform on the existence of strategic behaviours in these markets linked to the geographical location of the plants. Therefore this paper fills the gap of the studies on wholesale electricity markets´ bid pricing strategies by explicitly accounting for the importance of physical geography and the location of plants in their strategies.

The remaining part of the paper is divided into five additional sections. In the second section a brief review of the literature is made. In the third section the structure of the spot electricity generation market in Colombia is explained and the stylized facts of this market are presented. The fourth section contains a detailed explanation of the methodology. Additionally this section contains a description of the variables included in the analysis. The fifth section presents and discusses the econometric results. Finally, in the last section, the main conclusions of the analysis are drawn.

2. Literature review

The international literature on wholesale electricity markets´ price setting has resorted to the use of different models; supply models (Green and Newberry, 1992; Green, 1996), auction models (von der Fehr and Harbord, 1993 and Brunekreeft, 2001), Cournot-type oligopoly models (Fabra and Toro, 2005) and econometric models (Wolfram, 1998). In all these models the common feature is that the electricity generators generally have market power, which is strategically used to plan offers which raise the spot prices and increase profits. Other studies using less conventional techniques are those of Hurtado et al. (2014) who resort to the use of an artificial intelligence model or Geman and Roncoroni (2006) and Garcia et al. (2013) who use a model of mean reversion and a stochastic model respectively.

The market power of the electricity generators and its subsequent manifestation on the spot prices is affected not only by the oligopolistic nature of this industry but also by the strategic location of the plants from a geographical point of view. Physical geography influences weather conditions and therefore it also affects the geographical distribution of hydraulic generation (Laitinen et al., 2000; Mathiesen et al., 2013, Joskow and Kahn, 2002; Rangel, 2008; Schill and Kemfert, 2011). For instance Laitinen et al., 2000 and Mathiesen et al., 2013, argue that precipitations have a significant effect on the spot prices, which differs for summer and winter. This causes consumers to have different price elasticities of demand for each season and, therefore producers take different strategic behaviours depending on the season. Similarly, Joskow and Kahn (2002), using a counterfactual estimate of the 2000 electricity prices for California, shown how a reduction in the imports of electricity due to drought, has substantially increased the price of it in comparison with the previous two years where droughts were absent.

Recently, several studies have analysed the strategic behaviour of hydraulic generators with regard to spot price setting linked to location (Burnett and Zhao, 2014; Mathiesen et al. 2013; Schill and Kemfert, 2011; and Rangel 2008). These authors found that the location of generators and their management of reserves over time plays a major role in their spot price setting strategies. However, to the best of our knowledge there is no research that shows the role played by the geographical location of the electricity generators in their bid price setting strategies. This papers is a first attempt to do so for Colombia.

3. Colombian spot market of electricity generation: Structure and some stylized facts

3.1 Some stylized facts

The electricity generation activity in Colombia is largely dominated by hydraulic technology, supplying approximately between 65% and 80% of the energy, depending on the timing of the demand[1]. This causes the dependence on weather conditions to be crucial to have a reliable development of the system.

The electricity demand in the Colombia´s National Interconnected System (Known as Sistema Interconectado Nacional-SIN-) in 2014 was 63 GWh-year, with sustained increases in the last two years of around 3% (XM, 2015). The electric system in Colombia consists of four activities: generation, transmission, distribution and commercialization. This paper focuses on the first type of activities, in which the electricity is produced by the generators. The generators differ from each other by the type of plants they have which are classified in four categories: a) plants with installed capacity over 20 MW (in the Colombian terminology these plants are known as Plantas Despachadas Centralmente), b) plants with installed capacity below 20 MW (Plantas no Despachadas Centralmente) c) co-generators and d) self-generators. Only generators with plants in the classification a) and b) meet the requirements to participate in the Colombian electricity spot market.

[1]Large projects based on hydraulic technology, currently under construction, such as Pescadero-Ituango among others, lead us to believe that this situation will not change substantially in the coming years.

The activity of electricity generation works under economies of scale with high fixed costs and entry barriers. This leads to the existence of an oligopolistic market structure where the actors involved in this industry exercise their market power (Hurtado et al, 2014, Botero et al, 2013; Belleflamme and Peitz, 2010; Carlton and Perloff, 2004) by setting electricity prices above the total average operating costs.

In Colombia in 2014, approximately 61% of the electricity generation corresponds to the 3 largest industry players, while 82% is covered by the 6 largest agents[2]. In addition, in 2014, the installed capacity was mainly hydraulic (65.5%) and thermal (28.6%). The remaining installed capacity is made by smaller plants and co-generators (5%) (XM, 2015).

Electricity is a homogeneous good with a highly inelastic price demand in short-term periods. Gutiérrez (2011) and Zapata (2011) found that for the case of Colombia the elasticity varies between -0.067 and -0.12. Big information asymmetries, where the users know their consumption levels two months after having done it are the hearth of these high values. In addition, a huge effort in terms of coordination to match the bids with the demand forecasting is required to meet the demand in real terms.

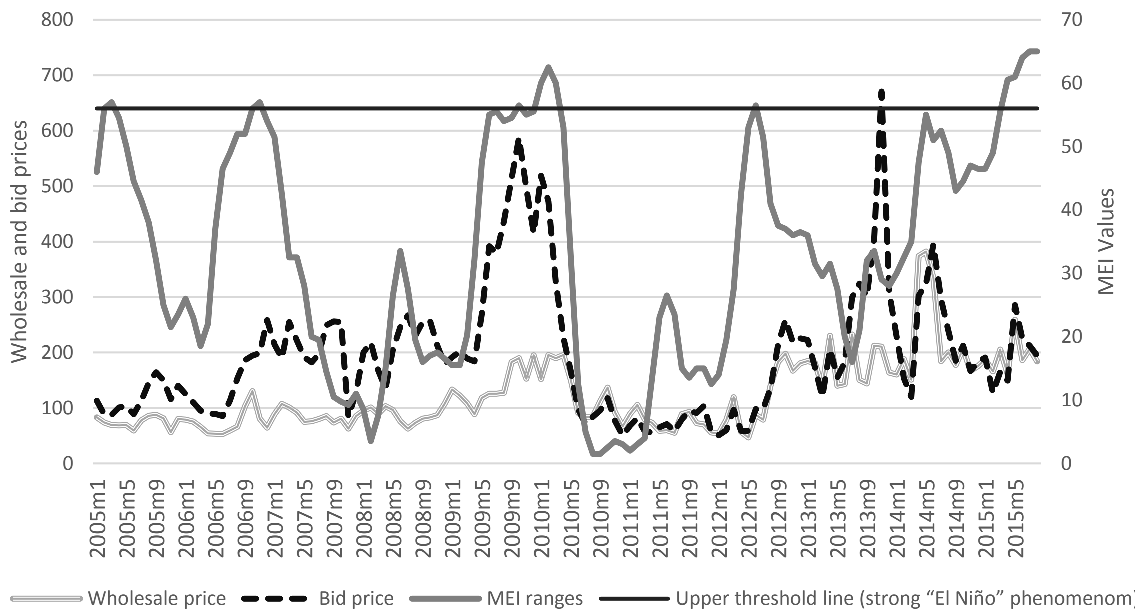
Given the high percentage of generation through hydraulic technology, the performance of the wholesale electricity market depends greatly on the weather conditions of the country. These conditions are heavily linked to the "El Niño" phenomenon. The information provided by the Multivariate ENSO Index (MEI) (NOAA, 2015), allows us a better understanding of the importance of "El Niño" in the performance of the market. When this index takes values between 44 and 56 represent an *intermediate* "El Niño" phenomenon, and when the index takes values between 56 and 61 represent a *stron*g "El Niño" phenomenon.

From the launching of the wholesale electricity market in 1995, the driest period took place with the 1997 "El Niño" phenomenon. Other periods in which "El Niño" phenomenon was active correspond to the first month of 2005, the last four months of 2006 and early 2007, the last six months of 2009 and the first four of 2010 and the last three months of 2014 and the first three months of 2015 (Figure 1). The large share of hydraulic component in the electricity generation in Colombia makes the positive correlation between "El Niño" and the spot price to be high (approx. 30%). However, it is also important to bear in mind the effect other variables related to the economic fundamentals of the Colombian wholesale electricity

[2] Currently in Colombian there are 17 power generation companies.

market, regulatory norms established by the gas and energy commission, regulatory risk aversion issues, etc., may have on the wholesale prices of electricity. In sum, the wholesale electricity market is a market with a fairly high level of complexity, where there are many variables that influence the price (Garcia et al, 2013; Hurtado et al., 2014; Santa Maria et al., 2009).

Figure 1. Wholesale price, bid price and MEI ranges, Colombia

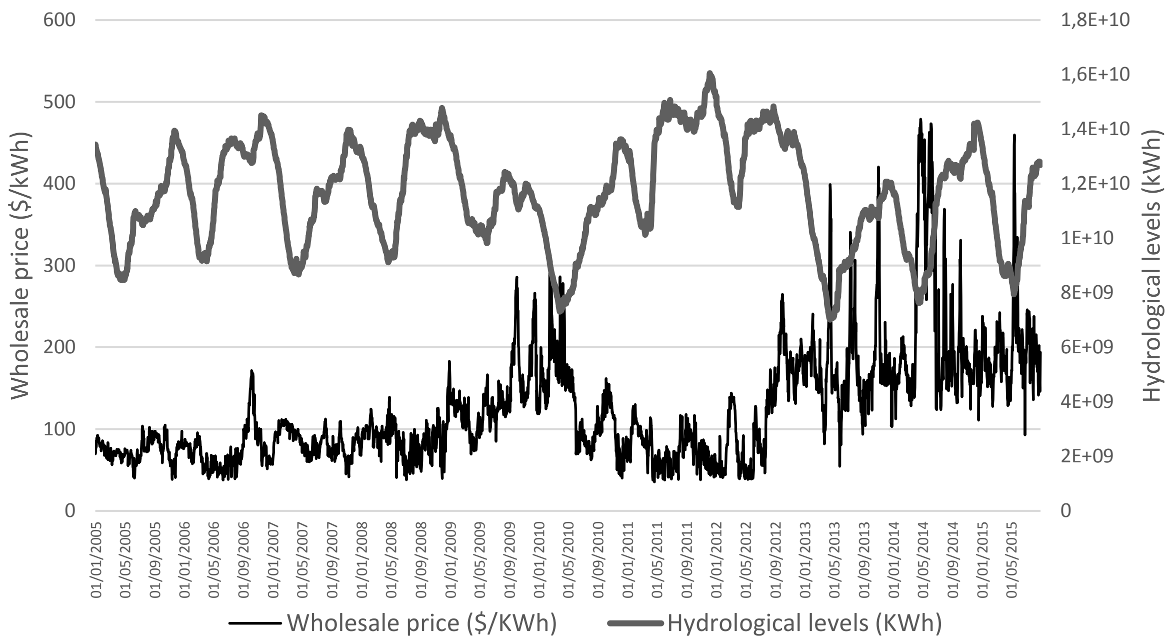


Note: MEI values above the upper threshold line represents a *strong* "El Niño" phenomenon.

Source: Own elaboration based on data from XM and NOAA, 2015.

Figure 2 shows the relationship between the average wholesale price and the hydrological levels. The measure of the hydrological levels includes mainly water reservoirs and the inputs from rivers and represents the total supply available nationwide for hydraulic generation. This causes that the negative correlation between hydrological levels and wholesale prices is of around 32%. Because hydrological levels represent the total supply available for a given period of time, movements in the chart that lead to a direct correlation cannot be observed. However, it can be seen in some periods, for example, in early 2010 a large drop in hydrological levels and a rise in the price. Also between 2013 and 2014 volatility in the hydrological levels resulting in greater price volatility can be observed.

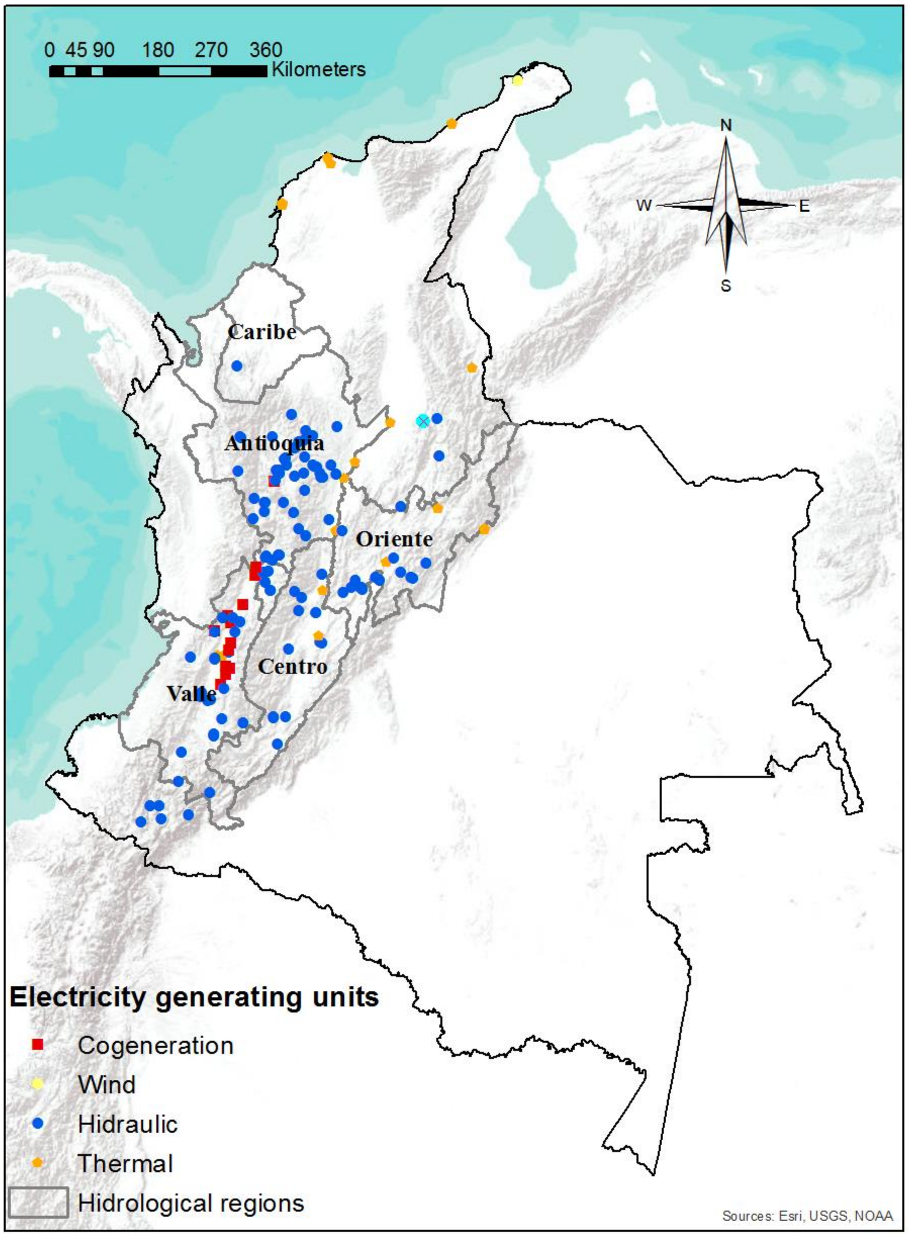
Figure 2. Wholesale price and hydrological levels, Colombia



Source: Own elaboration based on data from XM, 2015.

Most electricity generating plants are in the territory of the National Interconnected System (SIN). The Andean Region and the Central Atlantic Coast are mainly hydraulic generating regions whereas the Atlantic Coast is mainly a thermal generating region (see figure 2). This fact is not unrelated to the strategic geographical location of the generation plants. The type of source used to produce power is region-specific; the hydraulic generation is located in the Andean Region.

Figure 3. Location of electricity generating plants

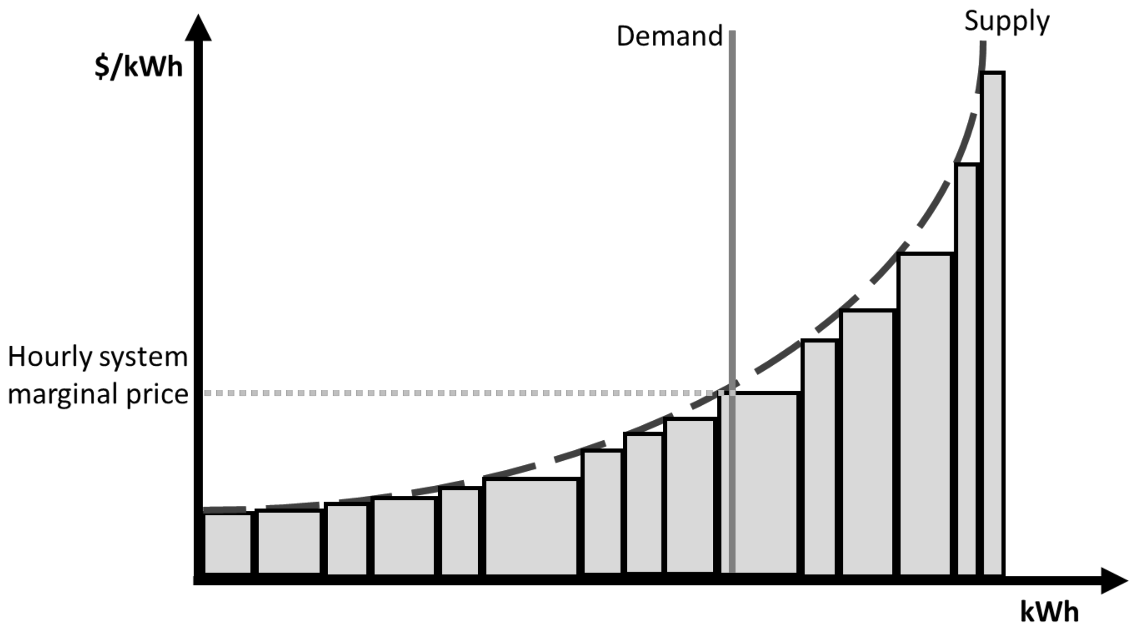


Source: Compiled from XM and the website of each generating company

3.2 The wholesale price mechanism

The Colombian wholesale electricity market is coordinated by the administrator, a company name XM. It operates as a “day-ahead” market: Every day is divided into 24 hour periods and a single price covers all purchases and sales in that hour period. Pool prices are based on bid schedules submitted daily by each generator detailing the prices at which they would be willing to supply power from each of the units they own obtaining a positive slope stepped supply curve. Using demand forecasts for the following day, the administrator determines a system marginal price (SMP) for each hour period based on the bid of the most expensive generating unit used to meet forecast demand. (see Figure 4).

Figure 4. System marginal price mechanism



Source: Own elaboration

In addition, taking into account that forecast demand does not necessarily coincides with the real-time demand, the administrator in accordance with the rules established by the regulator of the electricity market (known in Colombia as Comisión de Regulación de Energía y Gas-CREG), sets on top of the system marginal price an extra payment that is designated to compensate the generators for making their capacities available due to transmission constraints. These extra payments in the Colombian electricity market are known as *reconciliación positiva*[3] (positive reconciliation). These type of extra-payments which in this case refer to the payments given to generators due to the mismatch between demand forecast and real-time demand can also be given to guarantee the quality of the service (electricity) provided by the generators, technically known as *automatic generation control* (AGC).

4. Datasets and Descriptive statistics

4.1 Datasets

This study combines the use of two main datasets. The first one is provided by the Market Operator, XM, on its website www.xm.com.co under the heading "Portal BI". The second one is provided by the Department for National Statistics – DANE (www.dane.gov.co). "Portal BI" provides information for each electricity generation unit on the following variables:

Bid Price (BD), positive reconciliation (PR), electricity generation (GEN) and electricity inputs (IN). The first three variables are measured in COP[4]/kWh and last two ones are measured in kWh. BD and IN variables are provided daily whereas the remaining one are provided hourly. Information on the system marginal prices (SMP) which are measured in COP/kWh and provided hourly are also obtained via "Portal BI".

From these raw data, we have computed monthly averages for the price-variables and used monthly cumulated values for the quantity-variables over the period January 2005 to August 2015 for the 17 largest hydraulic plants.

We have also controlled for the economic cycle by using an index of industrial employment (IE) obtained from DANE.

[3] In the standard literature on electricity markets these extra payments are carried out in the so-called *balancing markets*

[4] COP is the international acronym for the Colombian currency (Peso Colombiano)

Table 3. Description of variables

Variable	**Units of measurement**	**Frequency** (raw data)	**Constructed data**
Bid Price (BD)	COP/kWh	daily	Monthly average
Positive reconciliation (PR)	KWh	hourly	Cumulated Monthly (daily average)
System marginal Price (SMP)	COP/kWh	hourly	Monthly average
Generation (GEN)	kWh	hourly	Cumulated monthly (daily average)
Electricity inputs (IN)	kWh	daily	Cumulated monthly
Industrial employment index (EI)	No units	monthly	Monthly

Source: Portal BI, XM and National Department of Statistics - DANE

4.2 Descriptive statistics by Hydrological Region

A first approach to the influence of the geographical location of generating plants[5] on the electricity bid prices in Colombia can be seen in table 1. This table gathers information on: the average bid price; electricity generation; the positive reconciliation; and the average electricity inputs of each of the hydrological regions determined by the market operator, XM. The hydrological regions show different means and standard deviations for each variable even though the country is interconnected. A first observation indicates that the spatial location of the electricity generating plants has an important effect on the variable electricity inputs, which shows significant differences depending on hydrological region.

[5]Corresponds to the power generation with the largest hydraulic plants of the market. They represent approximately 65% of the power generation which does not include the generation with thermal technology.

Table 1. Descriptive statistics

Variable	Units	Hydrological Region	Mean	Standard dev	Min.	Max.
BP	COP/kWh	Antioquia	103.81	79.95	28.37	561.01
		Caribe	167.15	130.68	27.77	678.96
		Centro	263.24	423.81	30.58	2598.28
		Oriente	95.04	90.98	27.77	1270.09
		Valle	497.06	629.33	36.31	3310.52
GEN	kWh	Antioquia	8,946,368	6,473,121	991,240	33,900,000
		Caribe	4,524,529	1,518,535	1,477,799	8,274,757
		Centro	4,140,286	3,667,998	41,452	13,400,000
		Oriente	16,400,000	5,201,984	3,194,778	35,300,000
		Valle	3,727,498	2,556,000	25,075	12,400,000
IN	kWh	Antioquia	269,000,000	188,000,000	23,700,000	1,820,000,000
		Caribe	112,000,000	51,000,000	15,600,000	215,000,000
		Centro	111,000,000	103,000,000	2,676,100	447,000,000
		Oriente	486,000,000	361,000,000	8,686,000	2,320,000,000
		Valle	90,000,000	71,600,000	3,419,900	331,000,000
PR	kWh	Antioquia	316,834	482,559	0	4,740,703
		Caribe	200,613	324,946	11,082	1,591,858
		Centro	440,325	632,385	654	3,770,229
		Oriente	1,049,850	1,289,723	127	8,921,401
		Valle	190,971	260,040	0	2,339,498

Source: Own elaboration

These differences in the observed means may be due to differences in the physical capabilities of the regions to generate electricity or to differences in weather conditions caused by the physical geography of the regions. Moreover and from a general perspective, the differences in electricity inputs caused by weather conditions could either be homogeneous or heterogeneous across the territory. In the particular case of Colombia we argue that the spatial heterogeneity is playing an important role on the level variation of electricity inputs. This fact is reflected in the bid price setting strategies of the electricity generating units.

Using the Spearman correlation coefficient[6] between the electricity inputs of each of the hydrological regions[7] (Table 2) it can be observed that two correlations are not statistically significant, Valle-Caribe and Valle-Oriente). These two correlations might imply that the electricity generating units located in those territories behave strategically with regard to their bid price setting strategies. For example, if electricity generating units located in the Valle region know that those located in the Oriente region have low hydrological levels, the electricity generating units located in Valle could exploit this situation by increasing their bid prices. Of course, in this decision is important to take into account the behavior of the demand. Thus, this preliminary analysis gives some hints about the potential effects of the plant location on the bid price setting strategies. In the next section a spatial econometric model which incorporates locational elements related to the generators is estimated. These locational features will become a key element in explaining the bid price setting strategies of the electricity generating plants in Colombia.

Table 2. Spearman's rank correlation coefficient for the Electricity inputs

	Energy inputs				
	Antioquia	Caribe	Centro	Oriente	Valle
Antioquia	1.000				
Caribe	0.628 0.000	1.000			
Centro	0.423 0.000	0.350 0.000	1.000		
Oriente	0.572 0.000	0.713 0.000	0.676 0.000	1.000	
Valle	0.375 0.000	-0.052 0.561	0.418 0.000	-0.036 0.691	1.000

Source: Own elaboration

5. Econometric specification

5. 1 Econometric specification

[6] This correlation is similar to the Pearson correlation, but is less vulnerable to extreme values that may arise in the series

[7] For development of the Spearman's rank correlation coefficient, see Conover (1999).

We depart from the ideas of Ivaldi et al. (2003) and Bernheim and Whinston (1990) to estimate the main factors influencing the bid price set by an electricity generating unit (BP). Our econometric model takes into account the following variables: the system marginal price (SMP), electricity generation (GEN), electricity inputs (IN) and payments by positive reconciliation (PR). An index of industrial employment (EI) is also added to capture the behaviour of the economic activity.

The estimated econometric specification is given by the following equation:

$$\ln BP_{it} = \beta_0 + \beta_1 lnSMP_t + \beta_2 lnGEN_{it} + \beta_3 IN_{it} + \beta_4 PR_{it} + \beta_5 IE_t + \varepsilon_{it}$$

$$\varepsilon_{it} : white\ noise \qquad (1)$$

Where the sub-indexes i and t stand for electricity generating unit and time period respectively.

BP is the bid price of electricity measured in (kWh) and expressed in logs

SMP is the system marginal price-expressed in Colombian pesos- of electricity measured in (COP/kWh) and expressed in logs

GEN is the electric generation measured in (kWh) and expressed in logs

IN are the energy inputs measured in (kWh) and expressed in logs

PR are the positive reconciliations paid to the firms measured in (KWh)

IE is an index of industrial employment

Eit is the error term

Equation (1) will be estimated by Pooled OLS using a sample of 2176 observations which correspond to the 17 largest electricity generating units with monthly data from January 2005 until August 2015.

5. 2 Estimation approach

5.2.1 Baseline estimation

Our point of departure consists of estimating equation (1) by Pooled OLS (Column #1). It can be seen that all the estimated coefficients are statistically significant and the signs are in line with the economic rationale of this type of markets. However one of the advantages of having a panel data is that it allows us to control for unobservable individual heterogeneity across our units of observation. In order to fit the best model both fixed and random effects are applied to the estimation of equation (1). The results of these estimations are shown in columns #2 and #3. Again, as in the Pooled OLS estimation, the coefficients are statistically significant and the signs according to the expectations. The Hausman test points us that the best model is the random effects model which does not reject the null hypothesis of random effects with a p-value of 0.0273.

Table 4. Results of non-spatial panel

VARIABLES	(1) Pooled OLS	(2) Fixed-effects (within) regression	(3) Random-effects GLS regression
Log National Stock price	0.798***	0.808***	0.809***
	(0.034)	(0.027)	(0.027)
Log Generation	-0.489***	-0.710***	-0.697***
	(0.017)	(0.027)	(0.026)
Industrial employment index	0.017***	0.016***	0.016***
	(0.004)	(0.003)	(0.003)
Energy inputs	-4.07e-10***	-1.14e-10*	-1.15e-10*
	(6.50e-11)	(6.24e-11)	(6.22e-11)
Log Positive Reconciliation	0.115***	0.089***	0.090***
	(0.008)	(0.007)	(0.007)
Constant	5.587***	9.253***	9.050***
	(0.566)	(0.585)	(0.587)
Observations	2,176	2,176	2,176
R-squared	0.529	0.500	0.502
Number of plants	17	17	17
Plant fixed effects		SI	NO
Moran's I	3.081		
LM Spatial Lag	62.195		
LM Spatial Error	8.564		
Robust LM Spatial Lag	151.171		
Robust LM Spatial Error	97.539		
Pesaran's test of cross sectional independence		3.750 (p=0.0002)	3.878 (p=0.0001)

Standard errors between parenthesis. *** p<0.01, ** p<0.05, * p<0.1
Source: Own elaboration

However in the electricity generating markets with a predominant share of hydraulic technology such as the Colombian case, the electricity generating units may have different strategic behaviours in their bid price setting strategies linked to the different geographic locations of the plants since climatic conditions vary quite drastically from one location to the other[8]. The influence of these type of location-specific strategic behaviours cannot be estimated with standard econometric techniques. A good avenue to go forward is by applying spatial econometrics. Moreover, positive spatial dependence among the residuals was found by using the Moran´s I test. The value of the test is 3.081 significant at 1% level[9]. The next subsection shows the results of our preferred specification.

5.2.2 Preferred estimation: a spatial Durbin model

In order to identify the right spatial econometric model we have followed Florax et al. (2003). It is important to bear in mind that Florax et al. (2003) recommendations are usually applied in a cross-section setting using Lagrange multiplier tests. In our case, due to the nature of the data (panel data) an adaptation of these tests has been carried out.

Florax et al. (2003) divides into two approaches the process to get the right spatial econometric specification: In the first approach we depart from a non-spatial model. This non-spatial model is tested by applying the Lagrange multipliers (LM spatial lag, LM Spatial error, Robust LM Spatial Lag, Robust LM Spatial error tests) to check for the existence of substantive or residual spatial dependence in the residuals of the pooled model. If these 4 tests reject the null hypothesis of non-spatial dependence, the model with the highest value in the tests is the one chosen. This first approach lead us to either estimate a spatial error model (SER) or a spatial lag model (SLM). However this election comes at a cost of neglecting a broad picture of the spatial dependence. To avoid this risk the second approach in Florax et al. (2003) propose the following: to depart from a Durbin spatial type of model and applied a) the common factor hypothesis to check for the validity of a spatial error model. In case of rejecting this hypothesis the next step is b) to apply the Wald test to check for the

[8] In a different setting, Wolfram (1998) analyses strategic behaviors of the electricity generating units in England and Wales to set their bid prices over marginal costs

[9] The Pesaran´s test rejects the null hypothesis of no-dependence across the units of analysis in the fixed and random effects models (electricity generating plants)

validity of a spatial lag model. If the null is rejected the data generating process corresponds to a spatial Durbin model[10].

We have followed these recommendations as it is shown in table 4 in order to get our preferred specification. The results of the Lagrange´s tests, both standard and robust, reject the null hypothesis of non-spatial dependence at the 1% significance level. Moreover, the highest value for the Lagrange statistics are obtained for the LM Spatial Lag (62.195) and Robust LM Spatial Lag (151.171) which points us to a spatial lag type of model specification (SLM). However, the estimation of a SLM could not capture the whole structure of the spatial dependence present in our data set. To corroborate this fact, and following Florax et al. (2003) recommendations, we have checked for the common factor hypothesis. The results of these tests are shown in table 5 for a Chi-square statistic with one degree of freedom with values of 23.77 and 7.98 (1% significance level) for the standard and robust versions respectively.

Therefore, based on the previous tests, our preferred specification corresponds to a Durbin Spatial model which takes the following econometric specification (2):

$$\ln BP_{it} = \beta_0 + \rho WilnBP_{it} + \beta_1 \ln(SMP) + \beta_2 lnGEN_{it} + \delta_1 W_i lnGEN_{it} + \beta_3 IN_{it} + \delta_2 W_i IN_{it} + \beta_4 PR_{it} + \delta_3 W_i PR_{it} + \beta_5 IE_{it} + \varepsilon_{it}.$$

$$\varepsilon_{it} : white\ noise \qquad (2)$$

Where the sub-indexes i and t stand for electricity generating unit and time period respectively and the definitions of the variables BP, SMP, GEN, IN, PR and IE are the same as in equation (1). Additionally, the spatial Durbin model takes into consideration the spatial lags of BP (WBP), GEN (WGEN), IN (WIN), and PR (WPR). The elements ($w_{ij}, i \neq j$) of the weighting matrix, W, represent the inverse of the Euclidean distance between plants "i" and "j". The distance values (d_{ij}) have been computed using data on the longitude and latitude of each electricity generating unit. The main diagonal takes the "0" values. Finally, W has been row-standardized to sum 1 to easy of interpretation.

The proposed weighting scheme jointly with the Colombian physical geography characterizes a situation in which the probability of having different climatic conditions

[10] For a more comprehensive analysis of this methodology see Florax et al. (2003)

increases with the distance between the plants and therefore this implies two things: a) The degree of similarity among the strategies of the plants increases the closer they are to each other, and b) the intensity of the strategic behavior among the plants increases the farther away they are to each other.

Finally, Eit is the error term.

Equation (2) is estimated by maximum likelihood using monthly data from January 2005 until August 2015 for the 17^{th} largest electric generating units. The panel is made up of 2.176 observations and it is strongly balanced.

Table 5 presents the results of estimating equation (2) with random effects since the Hausman´s test with a statistical value of 3.26 does not allow us to reject the null hypothesis. The coefficient estimates are presented jointly with the associated standard (open brackets) and robust errors (closed brackets). It can be seen that for the estimation with "standard errors" all the coefficients with the exception of those corresponding to the variables energy inputs and the spatial lag of the log of positive reconciliation are statistically significant and the signs are according to the theoretical expectations. In the estimation with "robust errors" the coefficient associated to the index of industrial employment also loses its significance. It is worth commenting the lack of significance of the variable energy inputs vis-à-vis the significance of its spatial lag and the significance of the variable log of positive reconciliation vis-à-vis with the lack of significance of its spatial lag. In the first case, the results tell us that in the bid price setting strategies of each electricity generating unit what matters the most is the relative level of energy inputs of its competitors. The negative sign of the spatial lag for the variable energy inputs implies that the higher the level of the energy inputs of the competitors the lower should be the bid price set by the electricity generating unit. In the second case, the lack of significance of the spatial lag is based on the absence of market for the payments for positive reconciliation (they are assigned by regulation). Therefore, each electricity generating unit does not factor in its bid price setting strategies the positive reconciliation of its competitors[11].

[11] The Wald tests shown in table 5 (in the robust estimations) do not reject the null hypothesis of non-joint significance of the spatial lags when the spatial lag of positive reconciliation is included. However, when this is excluded, the null hypothesis of non-joint significance is rejected. These results reinforce the idea that the spatial lags of energy inputs and generation gather the strategic effects link to the location the electricity generating units.

Finally, with regard to the spatial lag of log generation, its coefficient is negative which means that a decrease in the generation levels of the rivals increases the bid price set by our electricity generating unit. The reason of this negative relationship obeys mainly to two factors, one link to the nature of this market and the other link to the particular geographical features of Colombia. With regard to the first factor, the wholesale electricity market in Colombia is highly inelastic and therefore a shortage of generation automatically implies an increase in the bid price set by the company. According to the second factor, the different location of the electricity generating units, which at the same time imply different weather conditions, implies that the generation levels varies quite substantially among them. For instance, if the electricity generating units located in the Andean region are under a rainy season whereas those located in the Central Atlantic Coast are under a dry season, the first ones, knowing that there is a shortage of generation in the Central Atlantic Coast, will have incentives to set higher bid prices. This second factor, which is at the hearth of the goals of our paper, would be negligible if the geographical features of Colombia were homogeneous across the country.

Table 5. Results of the Durbin model

VARIABLES	(1) Random-effects
Log SMP	0.589
	(0.047)***
	[0.076]***
Log GEN	-0.679
	(0.026)***
	[0.065]***
IE	0.015
	(0.003)***
	[0.009]
IN	7.21e-11
	(8.01e-11)
	[1.24e-10]
Log PR	0.090
	(0.007)***
	[0.034]***
W*Log GEN	-0.202
	(0.079)**
	[0.114]*
W*IN	-3.72e-10
	(1.32e-10)***
	[1.82e-10]**
W* Log PR	-0.023
	(0.018)
	[0.038]
rho	0.211
	(0.041)***
	[0.077]***
Observations	2,176
R-squared	0.534
Number of plants	17
Wald test spatial lag x3	9.05 (p=0.0108)
Wald test spatial lag x3	3.21 (p=0.2006)
Wald test spatial lag x2	6.59 (p=0.0103)
Wald test spatial lag x2	3.15 (p=0.0761)
Wald test spatial error	23.77 (p=0.0000)
Wald test spatial error	7.98 (p=0.0185)
Hausman Test	3.26 (p=1.0000)

Standard errors between parentheses. *** p<0.01, ** p<0.05, * p<0.1

Robust standard errors between square brackets

Source: Own elaboration

The econometric results of table 5 are complemented by the computation of the marginal effects (table 6) which are broken down into direct and indirect effects following the methodology of Drukker et al. (2010).

In general terms, the direct effects can be attributed to the self-effect of the electricity generating unit; in contrast, the indirect effects can be divided into global spatial effects that are dynamically dispersed throughout the system and local spatial effects, attributed to the neighborhood context which is not extended beyond.

The results in table 6 show that the indirect effect associated to energy inputs is statistically significant and negative whereas the direct effect is not statistically significant. This is in line with the results obtained in table 5. This result shows that the spillover effects are greater than the own-effects. This indicates how important is the location of an electricity generating unit in comparison with the location of its rivals. That is, electricity generating units act strategically, not only by taking into account their location but also that of their rivals.

In relation to generation, it is worth remark that the indirect effect is quite sizeable (-0.465) representing around 40% of the total marginal effect of generation (-1.152). With regard to the positive reconciliation the indirect effect is not statistically significant, confirming the lack of a balancing market associated to the Colombian wholesale electricity market. Finally, the bid price-elasticity of generation is elastic (-1.152), whereas the bid price-elasticity of positive reconciliation is inelastic (0.081).

Table 6. Direct and Indirect effects (Average)

				Robust Estimation		
VARIABLES	Direct	Indirect	Total	Direct	Indirect	Total
Log SMP	0.592	0.153	0.744	0.591	0.161	0.753
	(0.039)***	(0.024)***	(0.037)***	(0.064)***	(0.068)**	(0.091)***
Log GEN	-0.688	-0.445	-1.133	-0.686	-0.465	-1.152
	(0.028)***	(0.094)***	(0.097)***	(0.071)***	(0.161)***	(0.183)***
IE	0.015	0.004	0.019	0.016	0.005	0.021
	(0.003)***	(0.001)***	(0.004)***	(0.010)	(0.005)	(0.015)
IN	6.04e-11	-4.46e-10	-3.85e-10	5.60e-11	-4.69e-10	-4.13e-10
	(7.44e-11)	(1.46e-10)***	(1.21e-10)***	(1.20e-10)	(1.91e-10)**	(1.55e-10)**
Log PR	0.091	-0.006	0.085	0.091	-0.010	0.081
	(0.007)***	(0.021)	(0.022)***	(0.035)**	(0.036)	(0.023)***

Standard errors between brackets ***p<0.01,**p<0.05,*p<0.1.

Source: Own Elaboration

6. Conclusions

Traditionally, the analysis of the bid price setting strategies in the wholesale electricity markets where the predominant generation technology is hydraulic, is carried out without considering the impact the spatial heterogeneity has on the weather conditions. Colombia's physical geography varies greatly throughout the territory which generates a sizeable differential impact on weather conditions across the country. The electricity wholesale market in Colombian is very much dependent on the different impact that "El Niño" phenomenon causes across the territory. Using monthly data over the period January 2005-August 2015 on bid prices, generation, energy inputs and positive reconciliation for the 17 largest hydraulic electricity generating units jointly with data on system marginal prices, employment industrial index and data gathering information on the specific location of the plants and the distance among them, this paper estimates a spatial Durbin model for the bid price setting strategies of the electricity generating units. This type of specification allows us to explicitly consider not only the different geographic location of the plants but also their location-based strategic behaviors.

This paper reports three main results with regard to the bid price setting strategies of the electricity generating units: first, the spatial lag of the energy inputs variable shows up as negative and statistically significant whereas the variable energy inputs do not. The economic rationale of this result is based on the oligopoly nature of this type of markets but in this case this effect is reinforced by the fact that we take explicitly into account the differences in weather conditions according to the location of the plants. Plants strategically impound water to offer it when the price is higher.

Second, the payments for positive reconciliation to the rivals do not show up as statistically significant. This is explained on account of the fact that in Colombia payments for positive reconciliation are established by the regulator (CREG) and, therefore, generators do not factor in the payments made to the rivals in their price setting strategies.

Third, the spatial lag of log generation is negative which is explained by on the one hand the inelastic nature of this market and on the other by the fact that the generation levels of the plants differ largely due to the different impact of weather conditions. This second factor, which is at the hearth of the goals of our paper, would be negligible if the geographical features of Colombia were homogeneous across the country.

One potential policy recommendation derived from our results is the need to implement a market for the positive reconciliation payments with the aim to give more efficient signals in the price setting strategies and avoid arbitrary interventions by the regulator in these markets as it happens in most electricity international markets such as California, JPM (New Jersey, Pennsylvania and Maryland), Nord Pool and the UK, among others.

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