Electricity Price Fundamentals in Hydrothermal Power Generation Markets Using Machine Learning and Quantile Regression Analysis

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Introduction

- **Liberalization process in electricity markets:** Weron (2006), Weron and Misiorek (2008), and Girish et al. (2013).

- **Electricity market dynamic:** Gil and Ochoa (2008).

Introduction

Characteristic of the electricity spot price (Girish and Vijayalakshmi, 2013; Huisman and Mahieu, 2003; Ciarreta et al., 2011)**:**

- Seasonal patterns.
- High volatility and dispersion.
- Mean reversion.
- Price spikes.
- Serial correlation.

Introduction

Group	Determinant	References
Market characteristics	Demand and supply Electricity imports-exports Market-clearing quantity Energy policy	(Deng and Oren, 2006; Mandal et al., 2007; Mosquera-López and Nursimulu, 2019; Zhang-Yun et al., 2008).
Fundamental factors	Fuel prices Weather Hydrological conditions	(Rodriguez and Anders, 2004; Zhang-Yun et al., 2008).
Operational factors	Load rate Electricity production Energy sources: nuclear, hydric, or thermal Line status and limits Power transmission costs	(Rodriguez and Anders, 2004; Zhang-Yun et al., 2008).
Strategic factors	Energy purchasing agreements Bilateral contracts Bidding strategy	(Crespo-Cuaresma et al., 2004; Kian and Keyhani, 2001; Rodriguez and Anders, 2004).
Historical factors	Electricity price lags Demand and supply lags Hydric reserve lags	(Ciarreta et al., 2011; Mandal et al., 2007).

Introduction

Hydrothermal power generation market (Mosquera-López et al., 2017a; Fernández-Blanco et al., 2017; Cotia et al., 2019) **:**

i. Significant differences in the marginal costs of the generation sector.

ii. A small renewable generation capacity.

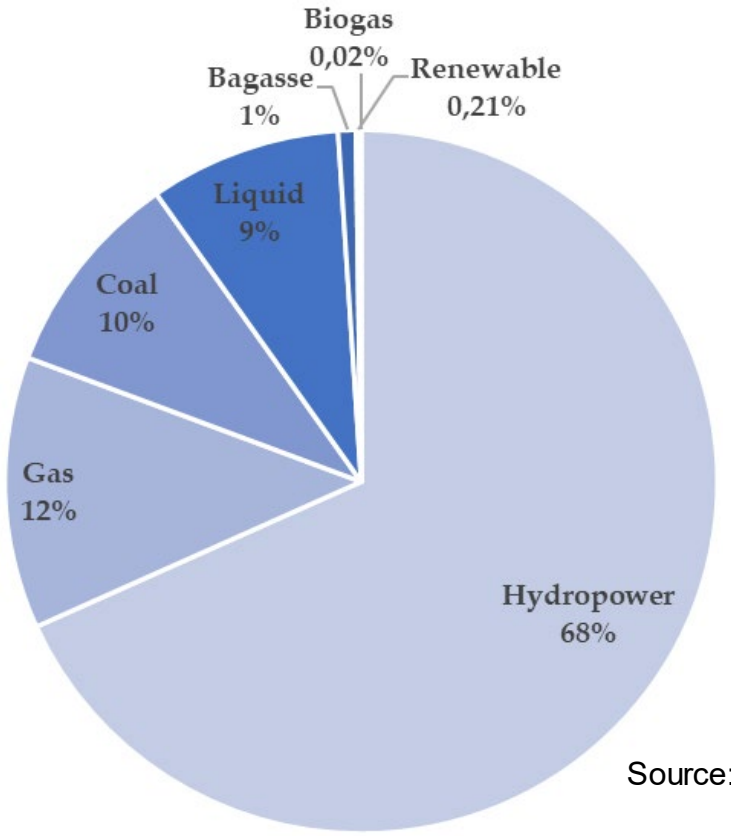
iii. A strong dependence on exogenous variables as fossil fuel prices and climatology factors.

iv. The risk and uncertainty are higher for market agents; it has been observed that these features cause further increased in price variability.

Introduction

The objective of this study was to identify the economic and technological fundamentals in the hydrothermal power generation market.

The Colombian electricity market

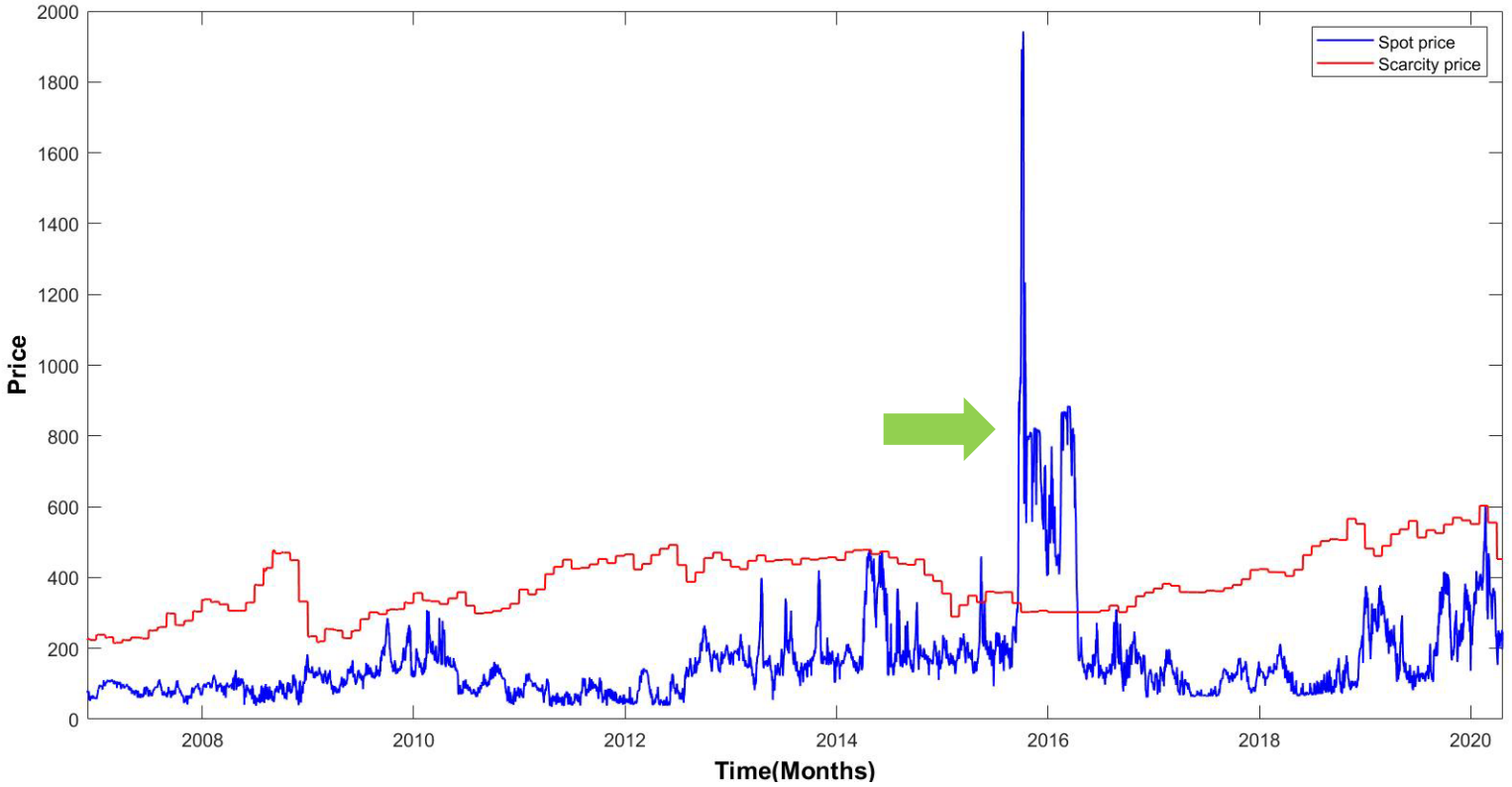


Source: XM Information System.

Power generation net capacity by technology for January 2020.

The Colombian electricity market

El Niño–Southern Oscillation (ENSO) and energy fossil price fluctuations (Botero-Duque et al., 2016; Montes, 2018)**:**



Electricity spot price dynamic for the period 2000-2020.

Source: XM Information System.

The Colombian electricity market

Determinant	*References*
▪ Weather changes. ▪ Fossil fuel. ▪ Electricity demand and supply. ▪ Power transmission power. ▪ Energy policy. ▪ Agent strategies.	Barrientos et al. (2012) Lira et al. (2009) Contreras et al. (2014) García et al.(2011) Castaño y Sierra (2012) Quintero e Isaza (2013)

Methodology

Machine learning (Castelli et al., 2020; Díaz et al., 2019; Gonzalez-Briones et al., 2019; Imani et al., 2020; Ribeiro et al., 2020)**:**

- Identifies complex patterns in a large volume of data.
- Reviews the data to predict future behavior.

Methodology

Machine learning:

- Gaussian Process Regression (GPR).
- Support Vector Machines (SVM).
- Tree-based methods.

Methodology

Performance indicators:

- **RMSE**

$$RMSE = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2\right)},$$

- $\boldsymbol{R^2}$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2},$$

- **MAE**

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|,$$

Methodology

Quantile regression (Koenker, 2004; Ma and Koenker, 2006; Uribe and Guillen, 2020)**:**

- Allows modeling electricity prices seasonality.
- Quantifying the non-linear effects of determinants.
- Captures the stochastic relationship between variables.
- Allows consistent estimation in non-Gaussian environmental.
- Requires a minimal distributional assumption on the data generating process.

Methodology

Quantile regression Koenker and Bassett (1978):

$$Q_q\left(Y_{i,t}\middle|X_{i,t}\right) = X'_{i,t}\beta_i^q,$$

where, $Y_{i,t}$ is a $(Tx1)$ vector, with T denoting the number of observations ($t = 1,2,3, \dots T$). Besides, the matrix $X'_{i,t}$ of dimensions (Txd), has $d-1$ predictors that also includes a constant, and β^q is a $(dx1)$ vector of unknown parameters for each quantile q, $q \in (0,1)$.

Data

- Balanced panel .
- Timespan: August 2009 – June 2019.
- Frequency: dialy ~ 3805 observations.
- Number of variables: 15.

Data

Electricity spot price ($/kWh)

- Average price.

Demand (MWh):

- Real.
- Commercial.
- National Interconnected System (NIS).

Reservoir levels – Climatology factors:

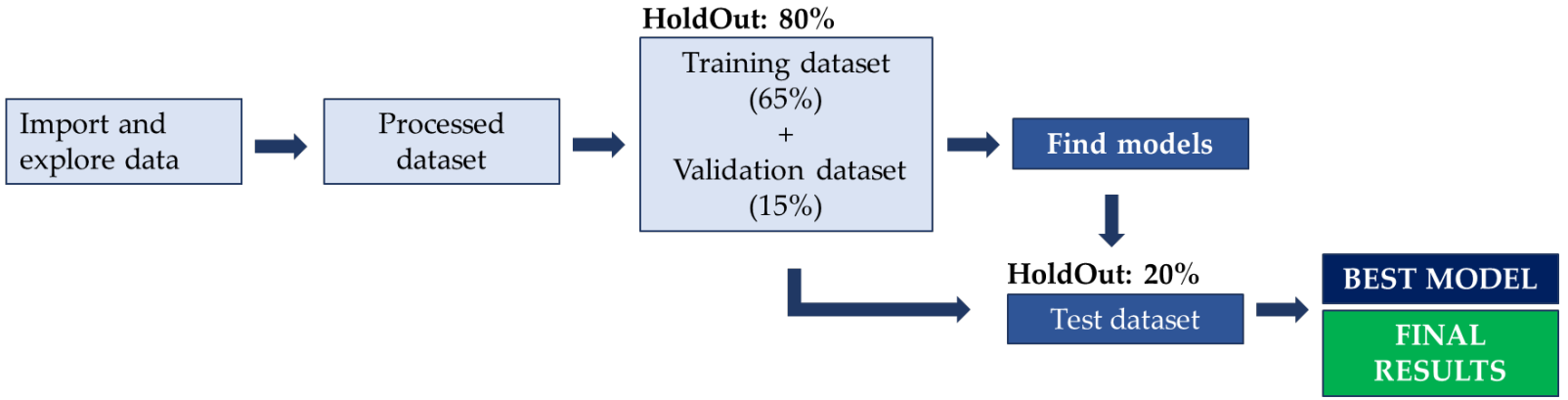
- Water resources (GWh).
- Historic water resources (GWh).
- Energy resources 95 (GWh)
- Daily volume (%).
- Daily Volume NIS (GWh).
- Generation capacity (MWh)

Fuel fossil consumption (MBTU):

- Coal.
- Gas.
- Fuel oil.
- Kerosene.
- Total consumption.

Data

Machine learning: Gaussian Process Regression



Demand (MWh):

- NIS.

Reservoir levels – Climatology factors:

- Daily volume (%).

Fuel fossil consumption (MBTU):

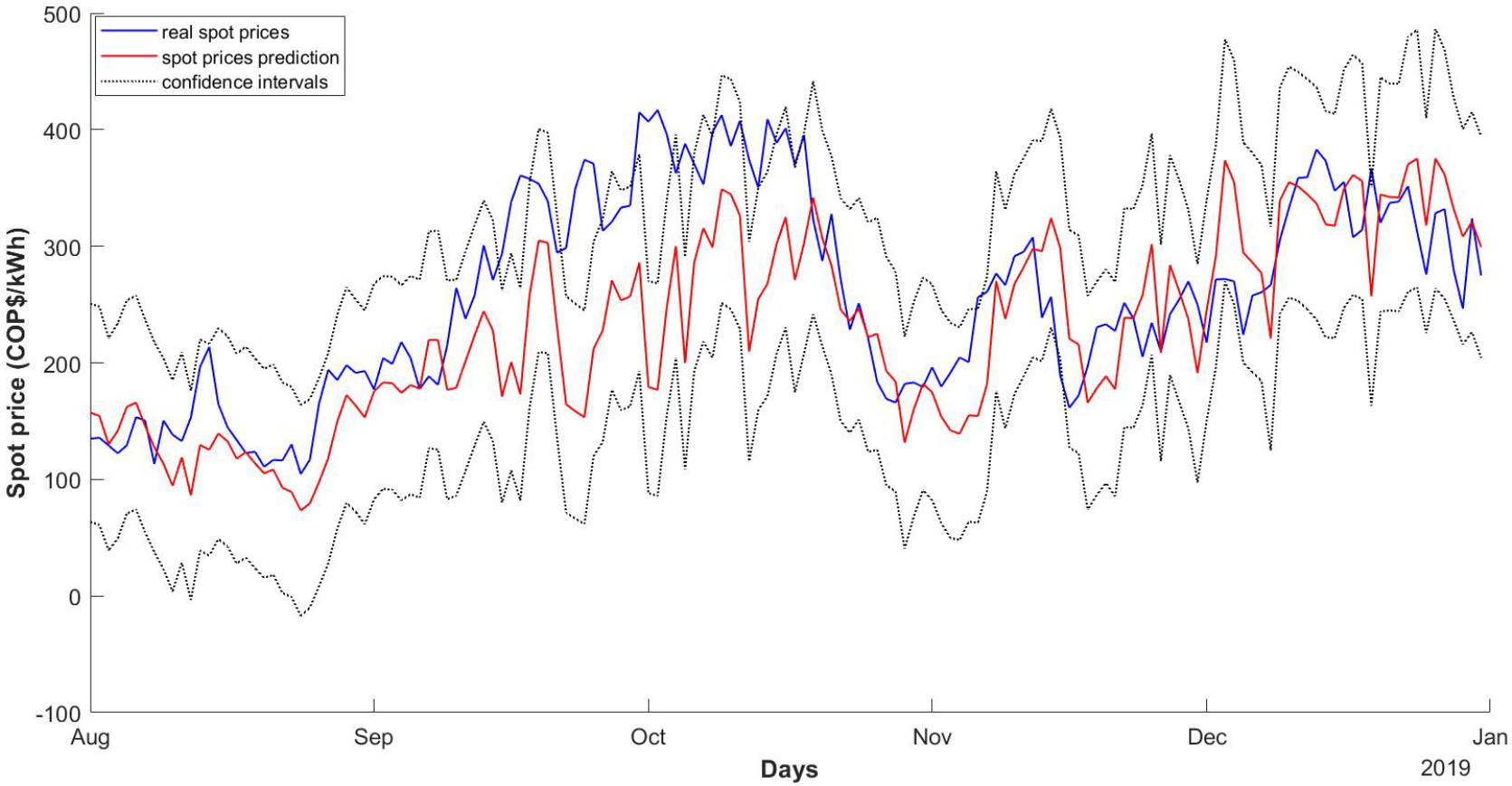
- Coal.
- Gas.

Electricity spot price ($/kWh)

- Average price.

Results

Machine learning: Gaussian Process Regression



Electricity spot price daily prediction for August 2019-December 2019.

Results

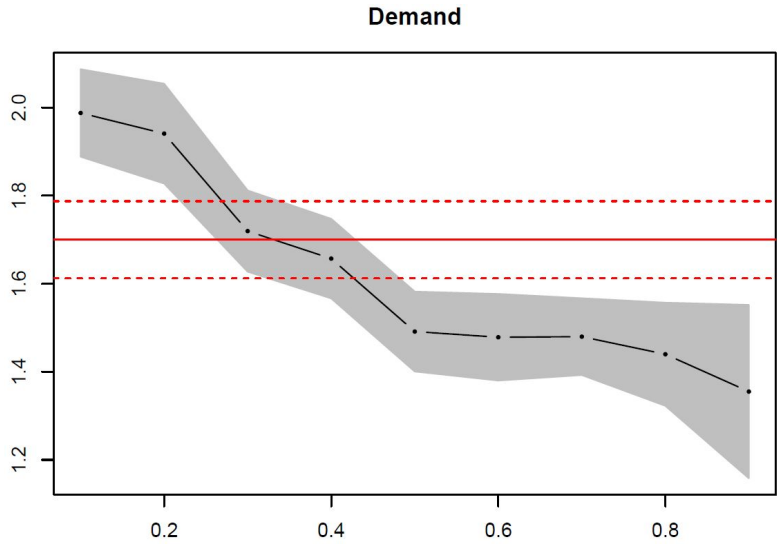
Quantile regression:

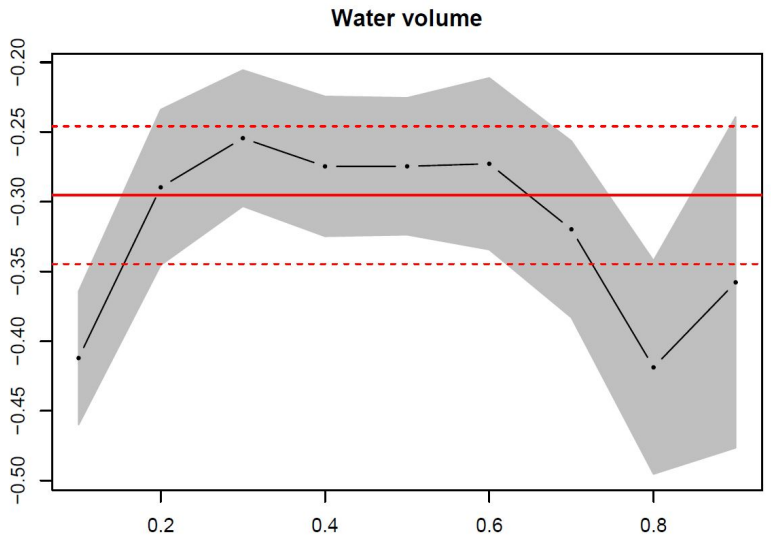
$$Q_q(P_{i,t}) = \beta_{i,1}^q + \beta_{i,2}^q D_t + \beta_{i,3}^q W_t + \beta_{i,4}^q C_t,$$

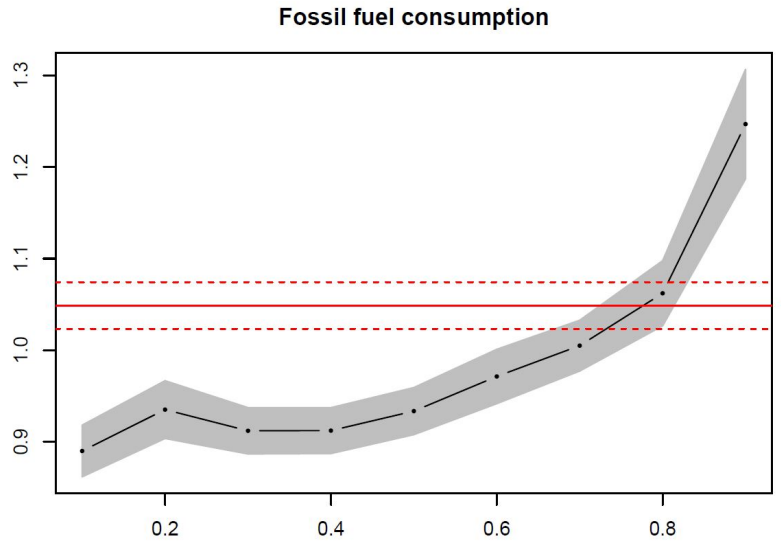
where, P_t is the response variable, spot price, while D_t is the demand, W_t is water volume, and C_t is the total gas and coal consumption. For estimating the quantile regression model, the period August 2009-December 2019 was used, and the natural logarithms were computed to interpret the coefficients as elasticities.

Results

Quantile regression:







Conclusions

- Positive changes were observed in the spot price through demand variations. When the electricity consumption increases, all generation technologies must produce to meet demand. However, if the demand is not cover, the thermal power generation plants must turn on, affecting the price.
- The elasticity of the water volume is negative, with increased impact on lower and higher quantiles. That is, seasonal patterns of reservoirs cause a strong price fluctuation, e.g., each rainy season, the spot price decrease significantly.
- Positive elasticities were found for fossil fuel consumption. It was revealed how gas and coal increased the price significantly on last quantiles. Exogenous effects such as dry seasons or the demand changes, increase the spot price through generation costs.
- An important aspect is the generation sector's influence on the price by future speculation of water volume; for this reason, it must be added a fundamental that captures the oligopoly structure.