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**Article**

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# Market Efficiency and Market Power in Vietnam Competitive Generation Market

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**ABSTRACT**

Market efficiency and market power are two major aspects in studying any type of market. Most of researches concentrated on either market power or market inefficiency rather than two in combination. In this study, the Vietnam Competitive Generation Market which has been operated from 2012 as a platform for day ahead competitive trading of electricity in Vietnam is analyzed for market efficiency and market power analysis to determine market performance. From empirical testing, evidence of market inefficiency is found. In addition, market power is also revealed by studying of the bidding behaviour of the biggest generating company.

**Keywords:** Market Efficiency, Market Power, Vietnam Competitive Generation Market
**JEL Classification:** Q4

## 1. INTRODUCTION

The electricity industry in Vietnam is now over a century old. The open economy policy of the government in 1990s led to the consolidation of the industry in order to expand its output capability to match the high demand of economy. Total energy was 160GWh in 2016. The total installed capacity reached 40,000 MW while the demand reached maximum capacity of 28,000 MW. The power sector in Vietnam is currently going through restructuring which is a recent trend over the world. Figure 1 shows the road map of electricity reform approved by the Government of Vietnam in 1993.

According to the road map, the first stage of power market development in Vietnam, Vietnam Competitive Generation Market (VCGM) began on 1st July 2012. In this stage, the competition on generation was started by using a bidding mechanism. The bidding mechanism creates a merit order based on the cheapest to highest bidding price considering transmission losses and constraints where generating units are located. Energy is traded through an integrated pool. All generators sell electricity to the electricity of Vietnam (EVN) which is Single Buyer in the power market. EVN provides electricity to Power Companies (PCs) on the basis of the bulk supply tariff. The PCs supply power to the end users based on regulated uniform tariff set by the government.

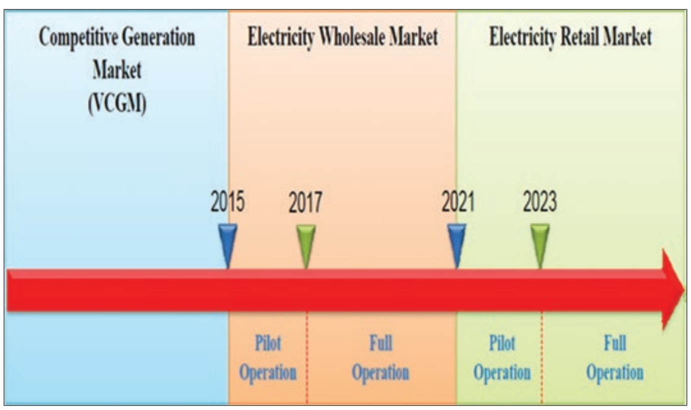
EVN is a state-owned vertical integrated utility in Vietnam that occupies 100% of transmission, distribution assets of Vietnam. On the generation side, EVN has around 55% of total system installed capacity. The rest belongs to independent producers. According to the road map of the electricity reform set by the government, the percentage of EVN generation assets would be reduced from time to time when the government gradually sells state-owned assets.

VCGM is a cost-based compulsory pool market where all electricity is traded through a day ahead market. Bidding revision during the trading day is not allowed. The day ahead bidding package of each generating unit includes five price-capacity range. The bidding price of one unit shall be lower than its cap price approved by the Regulatory Authority based on the short run marginal cost (SRMC) plus start up cost of the unit. The market settlement price is determined based on ex-post pricing mechanism on an hourly basis where cost to supply the last MW of electricity to meet the actual/metered demand without considering constraints of the generating units as well as transmission. Day ahead market price and hour ahead market price are indicative. The existence of contract for difference contract is to help both buyer and seller managing the risk of market price volatility (Marckhoff and Wimschulte 2009). The market price is set equal to the uniform marginal cost that does not take into account the transmission congestion. If the unit is dispatched based on the congestion at that time the offer price is higher than the market price, and the payment is made according to the offer price (constraint on payment).

Since it became fully operated from 1st July 2012, there have been many adjustments of market rules in order to improve the market performance. The VCGM explicitly causes many concerns about performance efficiency. The market price movements have indicated some abnormalities such as discreteness and deviations from SRMC of marginal units (vary from 600 VND/kWh to 1100 VND/kWh) and frequently fall to the floor price (0 VND/kWh). Actual market prices of VCGM from January 2013 to September 2014 are plotted in Figure 2.

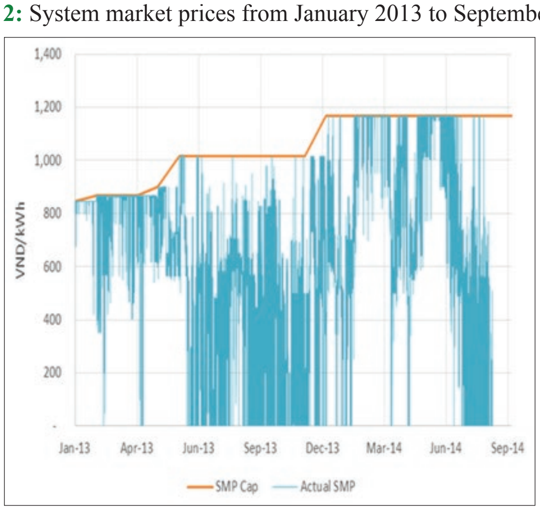
In this paper, an empirical analysis of the market data is used. Hourly market prices and the hourly bidding prices of all units of the biggest generating company in VCGM during 4 years from July 1st, 2012 are used to assess both the market efficiency and market power of VCGM. The outcomes from evaluating the actual market data are consistent with the market efficiency theory.

**Figure 1:** Vietnam road map for power market development




Source: Decision No. 63-2013- QD-TTd

**Figure 2:** System market prices from January 2013 to September 2014




Data source: EVN

## 2. CONTEXT OF THE RESEARCH

Market inefficiency and market power are often considered as the main cause of the problems experienced by many electricity markets (Borenstein and Bushnell, 1999; Brown and Olmstead, 2017; Baldick, 2016). A market is efficient when all the related information is fully and immediately reflected in market prices. In an efficient market, all market players are equally well–informed and control their bidding or offer strategies continuously to take advantageous opportunities. While the fundamental measure of market power is the price cost margin which measures the degree of how much the price exceeds the marginal cost. Market power is typically defined as the ability to profitably alter prices beyond competitive levels (Stoft, 2002; Pham, 2015). The price above marginal cost results in inefficient allocation because consumption would be too low in response to prices that are too high.

Research on market efficiency usually analyzes historical market prices in order to evaluate efficiency level. This indicates whether intervention activities from the market regulator to improve the market performance are effective or not. However, this kind of analysis does not provide alternative solutions to improve efficiency. In this case, an analysis of market power is required.

### 2.1. Efficiency Analysis

The efficient market hypothesis (FMH) is based on information availability (Fama, 1970). FMH proposes that when faced with new information, some investors may overreact and some may underreact. All that is required by the FMH is that investors' reactions be random and follow a normal distribution pattern so that the net effect on market prices cannot be reliably exploited to make an abnormal profit, especially when considering transaction costs including commissions and spreads(Fama, 1970).

According to Fama (1970), there are three different types of efficiency related to how efficient a market is in terms of information availability including weak-form efficiency, semi-strong-form efficiency and strong-form efficiency which are summarized in Table 1.

However, the strong form efficiency is somewhat impractical due to the limitations of private information in the real world.

### 2.2. Market Power Analysis

There are many methods of detecting market power in commodity markets. Unlike those markets, electricity markets have some distinctive characteristics to be considered as key aspects for market power measurement including market price reversion, the sudden fluctuation in consumption, fuel supply limitations, energy storage limitations and low elasticity in demand which is reflected in price spikes. In other markets, the concentration measures such as the Herfindahl-Hirschman Index (HHI) (Rhoades, 1993) are used. This was the first approach for detecting the potential market power. In the electricity market, the HHI measure is used to analyze power sector reform in many countries particularly the horizontal separation of generation. HHI is not perfectly suitable to investigate the market power in electricity market(Newberry, 2009). In recent years, many studies of market power monitoring

**Table 1: Three forms of market efficiency (Fama, 1970)**

| Efficiency form | Explanation |
|---|---|
| Weak form efficiency | Market prices fully incorporates historical price movements in future one |
| Semi form efficiency | Market prices adjusted to publicly available new information rapidly and in an unbiased fashion, no excess returns can be earned by trading on that information |
| Strong form efficiency | Prices reflect all public and private information and no one can earn excess returns |

have used two methods which seem to be the most suitable. Firstly, the residual supply index (RSI) (Sheffrin, 2002) which is a structural index in order to recognize the periods at which the generators exercise their market power is applied. Secondly, a more complex behavioural analysis is used typically based on real cost data or cost estimation, such as the price-cost mark-up (Hortacsu et al., 2017).

## 3. FRAMEWORK

### 3.1. Model 1: Market Efficiency Test

The methodology to analyse market efficiency in power markets follows related studies that focus on the market price movement of the power market. In order to determine a market which is efficient or not, the weak form should be first evaluated before other forms. This paper tests the weakest form of market efficiency called "weak form efficiency" according to Fama's efficiency forms (Fama, 1970). Specifically, a market is considered efficient when price changes follow a random walk model where future changes are independent of historical data. However, random walk theory only considers correlation in prices during different periods without considering the information availability or the transparency. It is only suitable to identify market efficiency in the weak form.

There are hypothesis tests to assess the random walk characteristics of a series but unit root tests are mainly used (Pham, 2015). Unit root tests identify whether a time series is stationary or non-stationary. A stationary test is used for evaluating the efficient market theory because it measures how data from different points in time depend on each other. In an electricity market, the weak market efficiency theory means that if market is weakly efficient, the future market prices cannot be predicted through analysis of historical market prices.

In this paper, the Augmented Dickey-Fuller (AFD) test is used for unit root tests (Glynn et al., 2007) where relationships among system marginal price (SMP) and day-ahead price are modelled by regression equations.

The AFD test requires the estimation of the following regression equation (Arciniegas et al., 2003):

$$\Delta P_t = \alpha+\beta_0 P_{t-1}+\sum\beta_1\Delta P_{t-1}+e_t \quad (1)$$

Where $\Delta P_t$ is the change in the electricity price at time t, $P_{t-1}$ is the electricity price at time t−1, α and $\beta_0$ are the coefficients, $e_t$ is residual.

Root tests are applied to the SMP, the day-ahead SMP. Moreover, the relationship between SMP and day-ahead SMP is also evaluated using co-integration analysis (Arciniegas et al., 2003). Two series are co-integrated if they grow at the same rate. In case of co-integration, market participants cannot make abnormal profits from day-ahead SMP data.

In order to test the relationship between the SMP and the day ahead SMP, two regressions using ordinary least squares method (Benoit, 2010) are used to test for bias:

$$SMP_t = C+\beta^*DASMP_{t-k}+e_t \quad (2)$$

$$SMP_t = C+\beta^*DASMP_{t-k}+e_t \quad (3)$$

Where:
- C is constant acting as intercept in linear regression.
- β is coefficient.
- $e_t$ is random term at time t.
- $SMP_t$ is actual spot price at time t.
- k is lag number determined by above lag determination section.

If the DASMP is a good predictor of SMP, the β coefficient will not be significantly different between equation 2 and 3.

### 3.2. Model 2: Market Power and Market Efficiency Test

The quantitative methodology based on historical market price data from VCGM and short run marginal unit costs as well as the bidding data of analysed firm is used in this paper. Firstly, RSI analysis will be implemented for the biggest generating company by using the hourly market prices, hourly market actual demands, hourly actual output of all other market generating companies. The result of RSI analysis will provide specific hours that the biggest generating company has market power. Secondly using actual SRMC, hourly bidding prices, declared capacity, actual available capacity and hourly metered energy for checking the real market power that the firm has actually exercised compared to the literature on market power in electricity (not including transmission congestion impacts). This analysis compares two results and evaluates the reliability of RSI in the VCGM.

## 4. RESULTS

### 4.1. Max-lag Determination

Outcomes obtained from AFD are sensitive to the choice of lag. Schwert's equation is to find maximum number of lag then specific number of lag is determined for selection using some criteria (Akaike information criterion, Schwarz information criterion) in order to optimize the AFD model.

Using the suggested formula from Schwert (Schwert, 2002), the maximum lag number is calculated as follows:

$$\text{Maxlag} = 12*\left(\frac{N}{100}\right)^{\frac{1}{4}} \quad (4)$$

Where N is number of observations.
With N = 26256, max-lag = 48.

## 4.2. Lag Determination

### *4.2.1. SMP series*

Table 2 shows lags by periods. The full lag numbers are in Appendix 1. The number of lag is selected in such a way that criteria values are minimum.

Using LR, FPE, AIC, SC, HQ criteria to choose lag number for SMP series is selected lag number of 48 based on the principle that the lowest value is the most appropriate one (Table 3).

### *4.2.2. DASMP series*

Similar to the SMP series, DASMP's lag number is selected of 48 based on the criterion of satisfying most indicators. The full lag numbers are shown in Appendix 2.

## 4.3. Testing for Stationarity

The ADF test is a common test for stationarity of time series because it can handle autoregressive time series which has an order higher than 1.

The null hypothesis is: $H_0$: The series is non-stationary.

The alternative hypothesis is: $H_a$ ($H_1$): The series is stationary.

Both SMP and Day-ahead SMP are tested by intercept-no trend ADF.

### *4.3.1. SMP series*

In this case, the P-value is less than all three significant levels. The Null hypothesis is rejected and the alternative hypothesis is accepted. This indicates that the SMP series is stationary, detailed in Table 4.

### *4.3.2. Day-ahead SMP (DASMP)*

Based on the analysis applied for the SMP series, the day-ahead SMP series also is stationary according to Table 5.

## 4.4. Relationship between SMP and Day-ahead SMP

The following regressions using ordinary least squares method are used to test for bias:

$$SMP_t = C+\beta*DASMP_{t-k}+e_t \quad (5)$$

$$SMP_t\text{-}SMP_{t-k} = C+\beta*(DASMP_{t-k}\text{-}SMP_{t-k})+e_t \quad (6)$$

Where:

- C is constant acting as intercept in linear regression.
- β is coefficient.
- $e_t$ is random term at time t.
- $SMP_t$ is actual spot price at time t.
- k is lag number determined by above lag determination section.

If the DASMP is a good predictor of SMP, the β coefficient will not be significantly different between equation 5 and 6.

Table 6 indicates β coefficient in equation 5 (0.621754) is neatly double compared to that in equation 6 in Table 7 (0.310730). This indicates that DASMP is not a good estimation of SMP.

# 5. MARKET POWER ANALYSIS

Market power (Twomey et al., 2006; Stoft, 2002) is defined as the ability to profitably raise prices in the power market because perfectly completive markets are impractical. Every generator attempts to exercise market power whenever it is available. Nevertheless, based on market power theory, a large-scale generating unit has more impact on the market price compared to small-scale one. In this paper, largest generator (Phu My EVN complex) is tested.

**Table 2: Brief description of lag determination on SMP series**

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | −191146.3 | NA | 126635.4 | 14.58694 | 14.58726 | 14.58705 |
| 12 | −164562.3 | 25.94821 | 16668.69 | 12.55916 | 12.56322 | 12.56047 |
| 24 | −163127.8 | 68.43436 | 14953.99 | 12.45061 | 12.45841 | 12.45313 |
| 36 | −162190.9 | 0.584158 | 13934.93 | 12.38003 | 12.39157 | 12.38376 |
| 48 | −161834.2 | 70.61675* | 13573.17* | 12.35373* | 12.36901* | 12.35866* |

*Indicates lag order selected by the criterion. LR: Sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion

**Table 3: Brief description of lag determination on DASMP series**

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | −190083.5 | NA | 116769.6 | 14.50584 | 14.50615 | 14.50594 |
| 12 | −169904.7 | 23.32750 | 25058.78 | 12.96686 | 12.97091 | 12.96817 |
| 24 | −167812.6 | 367.4963 | 21380.66 | 12.80812 | 12.81592 | 12.81064 |
| 36 | −166831.0 | 1.441162 | 19855.78 | 12.73413 | 12.74567 | 12.73785 |
| 48 | −166471.6 | 208.7474* | 19336.24* | 12.70761* | 12.72290* | 12.71255* |

*Indicates lag order selected by the criterion, LR: Sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion

**Table 4: Hypothesis test on SMP series**

| Null hypothesis: SMP has a unit root exogenous: Constant | | |
|---|---|---|
| Lag length: 48 (automatic - based on AIC, max-lag=48) | | |
| ADF test statistic | t-statistic | P* |
| Test critical values | −6.479239 | 0.0000 |
| 1% level | −3.430429 | |
| 5% level | −2.861459 | |
| 10% level | −2.566767 | |

*MacKinnon (1996) one-sided P values

**Table 5: Hypothesis test on DASMP series**

| Null hypothesis: DASMP has a unit root | | |
|---|---|---|
| Exogenous: Constant | | |
| Lag length: 48 (automatic - based on AIC, max-lag=48) | | |
| ADF test statistic | t-statistic | P* |
| Test critical values | −6.880209 | 0.0000 |
| 1% level | −3.430429 | |
| 5% level | −2.861459 | |
| 10% level | −2.566767 | |

*MacKinnon (1996) one-sided P values

**Table 6: Regression statistic for equation 5**

| Dependent variable: SMP | | | | |
|---|---|---|---|---|
| Method: Least squares | | | | |
| Date: 11/23/15 time: 08:12 | | | | |
| Sample (adjusted): 49 26256 | | | | |
| Included observations: 26208 after adjustments | | | | |
| Variable | Coefficient | Standard error | t-statistic | P |
| C | 281.6295 | 3.633968 | 77.49918 | 0.0000 |
| DASMP (−48) | 0.621754 | 0.005156 | 120.5948 | 0.0000 |
| $R^2$ | 0.356894 | Mean dependent variable | | 664.8530 |
| Adjusted $R^2$ | 0.356869 | SD dependent variable | | 355.8519 |
| SE of regression | 285.3770 | Akaike info criterion | | 14.14558 |
| Sum squared residual | 2.13E+09 | Schwarz criterion | | 14.14620 |
| Log likelihood | −185361.6 | Hannan-Quinn criteria | | 14.14578 |
| F-statistic | 14543.10 | Durbin-Watson stat | | 0.288833 |
| Prob (F-statistic) | 0.000000 | | | |

In the context of presence of vesting contract in VCGM, RSI is determined by the following equation (Sheffrin, 2002; Lin and Bitar, 2017).

$$RSI = \frac{\text{Total supply-Supply of largest seller}}{\text{Total demand}} \quad (7)$$

Where:
- Total supply: Total available capacity of all direct trading generators.
- Largest seller: Phu My power company consists of Phu My 1, Phu My 21, Phu My 4 power plants with total of 2400MW installed capacity. All units are Gas Combine Cycle using natural gas in southern Vietnam.
- Supply of largest seller: Largest seller's available capacity - contracted capacity.
- Total demand: Aggregated actual (metering) output of all direct trading generators.
- By calculating RSI of VCGM in all hours from 2012 to 2015, the number of hours which RSI lower than 110% are summarized I Table 8.

According to international experiences (Sheffrin, 2002; Asgari and Monsef, 2010), RSI must not be <110% for more than 5% of hours in a year (about 438 h). With a high contracted capacity (around 90%), the high possibility that market power exists in VCGM in 2014.

With the SMP setting methodology of VCGM, Phu My can exercise market power through bidding in two ways. Firstly, if it can manipulate the SMP, by raising at least the bidding price of the last band of the most expensive unit more than its SRMC. Secondly, it can do the same for any unit during the time those units are dispatched because of system congestion. If both bidding strategies succeed, Phu My would have much more benefit from raising the price because the dispatched production of all units are paid with the same SMP that is higher than the highest bidding price. In the second scenario, only the unit which has the bidding price higher SMP and was dispatched would be paid at this bidding price (pay as bid) and other unit's production would not be impacted.

**Table 7: Regression statistic for equation 6**

| Dependent variable: SMP-SMP (−48) | | | | |
|---|---|---|---|---|
| Method: Least squares | | | | |
| Date: 11/23/15 time: 08:25 | | | | |
| Sample (adjusted): 49 26256 | | | | |
| Included observations: 26208 after adjustments | | | | |
| Variable | Coefficient | Standard error | t-statistic | P |
| C | 16.18522 | 1.619039 | 9.996808 | 0.0000 |
| DASMP (−48) – SMP (−48) | 0.310730 | 0.006171 | 50.35311 | 0.0000 |
| $R^2$ | 0.088215 | Mean dependent variable | | 1.619994 |
| Adjusted $R^2$ | 0.088181 | SD dependent variable | | 270.0693 |
| SE of regression | 257.8871 | Akaike info criterion | | 13.94300 |
| Sum squared residual | 1.74E+09 | Schwarz criterion | | 13.94362 |
| Log likelihood | −182707.0 | Hannan-Quinn criteria | | 13.94320 |
| F-statistic | 2535.436 | Durbin-Watson stat | | 0.324941 |
| Prob (F-statistic) | 0.000000 | | | |

**Table 8: Number of hours that RSI lower than 110% in VCGM**

| Year | 2012 (half year) | 2013 | 2014 | 2015 (half year) |
|---|---|---|---|---|
| Number of hours that RSI lower than 110% | 220 | 318 | 1013 | 270 |

In this analysis, the action of raising the bidding price of the last band of the most expensive unit higher than SRMC is considered to impact the SMP and if that band is then dispatched and the SMP is equal to or higher than the bidding price, it is considered to be successful. By reviewing SRMC of the last band of bidding packages of all units during the sample time (35.000 h) in all hours from 2012 to 2015, with the constraint of RSI <110%, the number of hours that the maximum submitted bid prices are higher than the SRMC of the most expensive unit are clarified in Table 9 and also among those hour the number of hours Phu My succeed (the bidding price is lower than SMP) are showed in Table 10. The findings are that, 72.8% h Phu My submitted the highest bidding price higher than the SRMC of the most expensive unit and of which, 71.9% of times they succeed. In addition, in 2014 Phu My exercised market power only 65% of times but 94.2% of those times they did successfully. This result supports to the RSI theory because the more frequently that the VCGM capacity was scarcity the more chances for Phu My predicted the SMP better then they bided better.

During that time, at least 63% of hours that any generating unit from Phu My company successfully exercise its power to gain beneficial constraint-on payment (average price from constrain-on payment dominates SMP price), detailed in Table 11.

## 6. CONCLUSION AND RECOMMENDATION

The market power exercised by Phu My - the biggest market generator happened almost all of time that RSI <10% (72.8%) but less in the year during which RSI is <10% with the time of more than 5% (65%). This result can be explained that during the time of more serious system scarcity like 2014, the error of market demand forecast of Phu My is much higher compared with other periods. This made Phu My have a more conservative bidding strategy with the rate of successful bidding during this time higher compared with average level (94.2% vs. 71.9%). With the feature of a cost-based market like VCGM in which not any generator has the ability to exercise market power. The cap price of every generating unit regulated by the Regulatory Authority is also not high. The vesting contract coverage level is regulated at a high level (between 80% and 90% of overall energy production). The empirical findings demonstrate that the biggest generator tried to dominate SMP almost all of time they had a chance to consistent with the power market analysis in this section.

Because of market rules that regulate different cap prices for generating units with different SRMC, the Phu My company did achieve market power with the support of other generating companies with higher unit cap price. During those hours SMP were not always set by Phu My highest bidding price but by the higher bidding price of other companies. This finding demonstrates that smaller generating companies with higher

**Table 9: Number of hours that RSI < 110, max bidding > max SRMC**

| Year | Hours |
|---|---|
| 2012 | 220 |
| 2013 | 181 |
| 2014 | 659 |
| 2015 | 267 |
| 2016 | 0 |

**Table 10: Number of hours that RSI<110, SMP>max bidding, max bidding>max SRMC**

| Year | Hours |
|---|---|
| 2012 | 28 |
| 2013 | 39 |
| 2014 | 621 |
| 2015 | 267 |
| 2016 | 0 |

SRMC may exercise market power during time of system capacity scarcity.

This paper demonstrates that the VCGM is inefficient because evidence from 35,000 sampling hours indicates that VCGM's efficiency is not demonstrated to be the weak form regarding to the Fama theory shown in Table 1.

From the findings, in order to improve the market performance of the VCGM, the recommendations are:

Firstly, the contract vesting mechanism that is set the same for all market companies should be changed into a varying vesting mechanism, depending on the total capacity of each generating company. The higher vesting levels should be set for companies having bigger capacity and the lower should be set for lower capacity size limits. This methodology would reduce the opportunity for big generating market company like Phu My to exercise market power.

Secondly in the longer term, the difference cap price mechanism that is set different for each generating unit should be changed into using one cap price for the whole market. This means the hybrid market design of VCGM now (combination of cost based model and price based model) should be changed into a pure price based model. This change would avoid the situation of company having lower capacity size but higher SRMC to exercise market power. It would also avoid the risk of regulatory intervention that may happen during the process of setting too many cap prices for all generating units in the market.

Lastly, all market information and the regulatory processes should be informed equally to all market participants to increase market efficiency with limit market power in the VCGM.

**Table 11: Market power in terms of getting beneficial constraint-on payment**

| Unit | Number of hours with presence of Qcon and Rcon/Qcon>SRMP | Number of hours with precense of Qcon | Market power exercise-success rate (%) |
|---|---|---|---|
| GT11 | 4621 | 7072 | 65.34 |
| GT12 | 4469 | 6810 | 65.62 |
| GT13 | 4417 | 6992 | 63.17 |
| GT21 | 5273 | 7926 | 66.53 |
| GT22 | 5632 | 8356 | 67.40 |
| GT24 | 5751 | 8413 | 68.36 |
| GT25 | 5664 | 7933 | 71.40 |
| GT41 | 4981 | 7825 | 63.65 |
| GT42 | 4683 | 7144 | 65.55 |

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# APPENDIXS

**Appendix 1: Lag determination for SMP series**

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | −191146.3 | NA | 126635.4 | 14.58694 | 14.58726 | 14.58705 |
| 1 | −165043.2 | 52202.35 | 17277.22 | 12.59502 | 12.59564 | 12.59522 |
| 2 | −165031.4 | 23.44107 | 17263.08 | 12.59420 | 12.59514 | 12.59450 |
| 3 | −165014.3 | 34.22535 | 17241.87 | 12.59297 | 12.59422 | 12.59338 |
| 4 | −164949.8 | 128.9998 | 17158.50 | 12.58813 | 12.58969 | 12.58863 |
| 5 | −164904.3 | 90.90500 | 17100.38 | 12.58473 | 12.58660 | 12.58534 |
| 6 | −164898.7 | 11.19601 | 17094.38 | 12.58438 | 12.58657 | 12.58509 |
| 7 | −164892.1 | 13.18420 | 17087.08 | 12.58396 | 12.58645 | 12.58476 |
| 8 | −164882.9 | 18.39664 | 17076.39 | 12.58333 | 12.58614 | 12.58424 |
| 9 | −164840.2 | 85.46959 | 17022.07 | 12.58014 | 12.58326 | 12.58115 |
| 10 | −164671.6 | 337.0134 | 16805.77 | 12.56735 | 12.57079 | 12.56846 |
| 11 | −164575.3 | 192.6030 | 16683.94 | 12.56008 | 12.56382 | 12.56129 |
| 12 | −164562.3 | 25.94821 | 16668.69 | 12.55916 | 12.56322 | 12.56047 |
| 13 | −164560.5 | 3.511674 | 16667.73 | 12.55911 | 12.56347 | 12.56052 |
| 14 | −164549.7 | 21.70657 | 16655.19 | 12.55835 | 12.56303 | 12.55987 |
| 15 | −164505.6 | 88.10920 | 16600.53 | 12.55507 | 12.56006 | 12.55668 |
| 16 | −164297.3 | 416.2227 | 16340.05 | 12.53925 | 12.54455 | 12.54096 |
| 17 | −164167.2 | 260.0653 | 16179.83 | 12.52940 | 12.53501 | 12.53121 |
| 18 | −163999.3 | 335.6152 | 15975.02 | 12.51666 | 12.52258 | 12.51857 |
| 19 | −163905.1 | 188.2922 | 15861.78 | 12.50955 | 12.51578 | 12.51156 |
| 20 | −163831.6 | 146.9073 | 15774.25 | 12.50401 | 12.51056 | 12.50613 |
| 21 | −163594.2 | 474.3838 | 15492.24 | 12.48597 | 12.49283 | 12.48819 |
| 22 | −163324.4 | 539.0214 | 15177.75 | 12.46546 | 12.47264 | 12.46778 |
| 23 | −163162.1 | 324.4537 | 14991.98 | 12.45315 | 12.46063 | 12.45557 |
| 24 | −163127.8 | 68.43436 | 14953.99 | 12.45061 | 12.45841 | 12.45313 |
| 25 | −162307.0 | 1639.921 | 14047.15 | 12.38805 | 12.39616 | 12.39067 |
| 26 | −162224.6 | 164.6632 | 13960.14 | 12.38184 | 12.39026 | 12.38456 |
| 27 | −162199.9 | 49.43380 | 13934.87 | 12.38003 | 12.38876 | 12.38285 |
| 28 | −162198.7 | 2.427250 | 13934.64 | 12.38001 | 12.38905 | 12.38293 |
| 29 | −162198.6 | 0.008437 | 13935.70 | 12.38009 | 12.38944 | 12.38311 |
| 30 | −162196.0 | 5.217272 | 13933.98 | 12.37996 | 12.38963 | 12.38309 |
| 31 | −162192.8 | 6.540947 | 13931.57 | 12.37979 | 12.38977 | 12.38301 |
| 32 | −162192.7 | 0.133358 | 13932.56 | 12.37986 | 12.39015 | 12.38318 |
| 33 | −162192.7 | 0.008714 | 13933.62 | 12.37994 | 12.39054 | 12.38336 |
| 34 | −162191.5 | 2.420441 | 13933.39 | 12.37992 | 12.39084 | 12.38345 |
| 35 | −162191.2 | 0.515247 | 13934.18 | 12.37998 | 12.39120 | 12.38360 |
| 36 | −162190.9 | 0.584158 | 13934.93 | 12.38003 | 12.39157 | 12.38376 |
| 37 | −162188.8 | 4.306715 | 13933.70 | 12.37994 | 12.39179 | 12.38377 |
| 38 | −162187.7 | 2.207849 | 13933.59 | 12.37993 | 12.39210 | 12.38386 |
| 39 | −162187.0 | 1.370407 | 13933.92 | 12.37996 | 12.39243 | 12.38399 |
| 40 | −162167.7 | 38.41006 | 13914.55 | 12.37857 | 12.39135 | 12.38270 |
| 41 | −162134.9 | 65.64050 | 13880.74 | 12.37613 | 12.38923 | 12.38037 |
| 42 | −162108.3 | 53.01008 | 13853.71 | 12.37419 | 12.38760 | 12.37852 |
| 43 | −162103.3 | 10.11037 | 13849.41 | 12.37388 | 12.38760 | 12.37831 |
| 44 | −162094.0 | 18.56409 | 13840.65 | 12.37324 | 12.38728 | 12.37777 |
| 45 | −162037.7 | 112.2465 | 13782.44 | 12.36903 | 12.38337 | 12.37366 |
| 46 | −161970.3 | 134.7022 | 13712.71 | 12.36396 | 12.37861 | 12.36869 |
| 47 | −161869.6 | 200.9374 | 13608.82 | 12.35635 | 12.37132 | 12.36118 |
| 48 | −161834.2 | 70.61675* | 13573.17* | 12.35373* | 12.36901* | 12.35866* |

*Indicates lag order selected by the criterion, LR: Sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion

**Appendix 2: Lag determination for DASMP series**

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | −190083.5 | NA | 116769.6 | 14.50584 | 14.50615 | 14.50594 |
| 1 | −170413.3 | 39337.31 | 26028.68 | 13.00483 | 13.00545 | 13.00503 |
| 2 | −170371.6 | 83.32656 | 25948.02 | 13.00173 | 13.00266 | 13.00203 |
| 3 | −170366.8 | 9.770553 | 25940.33 | 13.00143 | 13.00268 | 13.00183 |
| 4 | −170254.7 | 224.1497 | 25721.33 | 12.99295 | 12.99451 | 12.99346 |
| 5 | −170165.7 | 177.9745 | 25549.17 | 12.98624 | 12.98811 | 12.98684 |
| 6 | −170149.4 | 32.54858 | 25519.39 | 12.98507 | 12.98725 | 12.98578 |
| 7 | −170121.0 | 56.69612 | 25466.17 | 12.98298 | 12.98548 | 12.98379 |
| 8 | −170120.9 | 0.205965 | 25467.92 | 12.98305 | 12.98586 | 12.98396 |
| 9 | −170086.3 | 69.28034 | 25402.60 | 12.98048 | 12.98360 | 12.98149 |
| 10 | −169988.4 | 195.6735 | 25215.49 | 12.97309 | 12.97652 | 12.97420 |
| 11 | −169916.4 | 143.9773 | 25079.19 | 12.96767 | 12.97141 | 12.96888 |
| 12 | −169904.7 | 23.32750 | 25058.78 | 12.96686 | 12.97091 | 12.96817 |
| 13 | −169896.1 | 17.19376 | 25044.25 | 12.96628 | 12.97064 | 12.96769 |
| 14 | −169894.6 | 2.890606 | 25043.40 | 12.96624 | 12.97092 | 12.96775 |
| 15 | −169869.9 | 49.47344 | 24998.04 | 12.96443 | 12.96942 | 12.96604 |
| 16 | −169720.4 | 298.7527 | 24716.41 | 12.95310 | 12.95840 | 12.95481 |
| 17 | −169472.1 | 496.2622 | 24254.33 | 12.93423 | 12.93984 | 12.93604 |
| 18 | −169281.3 | 381.3917 | 23905.49 | 12.91974 | 12.92567 | 12.92165 |
| 19 | −169197.8 | 166.9086 | 23755.43 | 12.91344 | 12.91968 | 12.91546 |
| 20 | −169164.5 | 66.49451 | 23696.99 | 12.91098 | 12.91753 | 12.91310 |
| 21 | −168883.0 | 562.4595 | 23195.19 | 12.88958 | 12.89644 | 12.89179 |
| 22 | −168393.8 | 977.6529 | 22346.84 | 12.85232 | 12.85949 | 12.85463 |
| 23 | −167996.5 | 793.7688 | 21681.22 | 12.82208 | 12.82956 | 12.82450 |
| 24 | −167812.6 | 367.4963 | 21380.66 | 12.80812 | 12.81592 | 12.81064 |
| 25 | −167131.6 | 1360.693 | 20299.43 | 12.75623 | 12.76433 | 12.75884 |
| 26 | −166961.5 | 339.7593 | 20039.23 | 12.74332 | 12.75174 | 12.74604 |
| 27 | −166881.4 | 160.0758 | 19918.59 | 12.73729 | 12.74602 | 12.74011 |
| 28 | −166864.0 | 34.67245 | 19893.75 | 12.73604 | 12.74508 | 12.73896 |
| 29 | −166861.2 | 5.768472 | 19890.88 | 12.73589 | 12.74525 | 12.73892 |
| 30 | −166849.8 | 22.59367 | 19875.24 | 12.73511 | 12.74478 | 12.73823 |
| 31 | −166842.2 | 15.18700 | 19865.23 | 12.73460 | 12.74458 | 12.73783 |
| 32 | −166841.7 | 1.153874 | 19865.87 | 12.73464 | 12.74493 | 12.73796 |
| 33 | −166839.3 | 4.781950 | 19863.75 | 12.73453 | 12.74513 | 12.73795 |
| 34 | −166836.8 | 4.836134 | 19861.60 | 12.73442 | 12.74534 | 12.73795 |
| 35 | −166831.7 | 10.22498 | 19855.36 | 12.73411 | 12.74533 | 12.73773 |
| 36 | −166831.0 | 1.441162 | 19855.78 | 12.73413 | 12.74567 | 12.73785 |
| 37 | −166826.0 | 10.00648 | 19849.70 | 12.73382 | 12.74567 | 12.73765 |
| 38 | −166823.3 | 5.362924 | 19847.15 | 12.73369 | 12.74586 | 12.73762 |
| 39 | −166822.9 | 0.864256 | 19848.01 | 12.73374 | 12.74621 | 12.73776 |
| 40 | −166813.7 | 18.28319 | 19835.66 | 12.73311 | 12.74590 | 12.73724 |
| 41 | −166796.1 | 35.25550 | 19810.46 | 12.73184 | 12.74494 | 12.73607 |
| 42 | −166778.2 | 35.60170 | 19785.03 | 12.73056 | 12.74397 | 12.73489 |
| 43 | −166772.5 | 11.40059 | 19777.92 | 12.73020 | 12.74392 | 12.73463 |
| 44 | −166771.1 | 2.888483 | 19777.25 | 12.73016 | 12.74420 | 12.73470 |
| 45 | −166731.9 | 78.31295 | 19719.64 | 12.72725 | 12.74159 | 12.73188 |
| 46 | −166655.2 | 153.0643 | 19606.10 | 12.72147 | 12.73613 | 12.72621 |
| 47 | −166576.1 | 157.8082 | 19489.67 | 12.71552 | 12.73049 | 12.72035 |
| 48 | −166471.6 | 208.7474* | 19336.24* | 12.70761* | 12.72290* | 12.71255* |

*Indicates lag order selected by the criterion, LR: Sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion