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Co-Integration Analysis Of Rtm And Dam In Indian Electricity Market

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Abstract

The launch of the real-time electricity market, which provides electricity on a real basis, i.e., with a lead time of only 1.5 hours, has offered new opportunities to different market players in the Indian wholesale electricity market. While it is true that real time market will provide greater flexibility, it can also lead to trading inefficiencies. This paper analyses the efficiency between the real-time market and the day-ahead market of the Indian electricity sector using Johansen co-integration test. Hourly price data is taken for two periods, i.e., June 2020 – March 2021 and April 2021 – March 2022. This research suggests that efficiency has decreased in the second year, which could provide arbitrage opportunities to various market participants.

Index Terms - Real-Time Market, Day-Ahead Market, Indian Energy Exchange, Johansen Cointegration Test

INTRODUCTION

The Electricity Act 2003 paved the way for the deregulation of the electricity market in India. Since then, many steps have been taken to efficiently discover the price and functioning of the deregulated electricity market. The launch of the real-time market (RTM) is a move taken in the same direction.

Over the last decade, different new products and market segments have been launched for the efficient functioning of wholesale electricity market in India mentioned in table 1.

Table 1

Product Name	Product Attributes	Trading Characteristics	Matching Mechanism
Day Ahead Market	Power from all the sources- conventional and non-conventional power	Deliveries in 24 hours of next day	Double side anonymous auction bidding
Green Day Ahead Market	Power from only non-conventional sources of energy	Deliveries in 24 hours of next day	Double side anonymous closed auction bidding
Term Ahead Market	Power from all the sources- conventional and non-conventional power	Different contracts such as Intra Day for delivery on same day, Day Ahead Contingency for delivery on the same day and Weekly for a duration of upto 11 days ahead	Intraday contracts and Day ahead contingency – continuous trading process Daily contracts – Trading on Rolling Basis Weekly contracts – trading through open auction on every Wednesday
Green Term Ahead Market	Power from only non-conventional sources of energy	Different contracts such as Green Intra Day for delivery on same day, Green Day Ahead Contingency for delivery on same day, Green Daily and Weekly for a duration of up to 11 days ahead.	Green intraday, Green DAC and Green daily contracts – continuous trading Green Weekly – Double sided open auction bidding process
Real Time Market	Power from all the sources- conventional and non-conventional power	Deliveries with a time lag of 1.5 hours on the same day	Continuous trading
Renewable Energy Certificates (REC)	green attributes of electricity generated from a renewable energy source	Solar REC and Non– Solar REC	Closed double side auction on the last Wednesday of every month

Source: IEX

Day ahead and real time market

Real-time market started in June 2020 and allowed different electricity entities to buy or sell data with a lag time of only 1.5 hours with continuous trading. It follows continuous bidding with 48 bid sessions in a day for delivery after 1 hour of gate closure of a particular session The day-ahead market uses double side anonymous auction bidding in the two hours session 1000hrs to 1200 hrs for delivery on the next day. The market-clearing prices are determined separately for both markets, which is referred to as multi-settlement systems.[1] At Indian Energy Exchange, the day ahead transactions are settled at day ahead prices and are binding; similarly, real-time transactions are settled at real-time prices and are binding for the participants. Different market-clearing prices may provide opportunity trade to various participants.[1] Electricity markets worldwide are characterized by multiple problems such as market power, market inefficiency and inelastic demand.[2] The growth of electricity markets requires strengthening the market monitoring system and close monitoring as the multiplicity of prices and interplay between various market segments can provide arbitrage opportunities. There arise dangers of gaming as discussed in CERC Discussion Paper “Market-based Economic Dispatch of Electricity – Redesigning Day-ahead Market (DAM) in India.” The discussion paper comments emphasize the need for market strengthening to prevent gaming by generators and distribution companies. The objective of this paper is to measure the efficiency in Indian electricity market.

The study has used hourly day ahead and real-time prices collected from IEX website. Two years are selected for the analysis from the launch of RTM market i.e. June 2020 – March 2021 and April 2021 – March 2022. Initially, we begin by looking at the pattern of the hourly price series of both the markets through maximum and average MCP for the two sample periods. The MCP of all days in a year is averaged for each hour in both the markets (Fig1 & Fig2). The average MCP graph shows that both markets follow the same trend and are similar in shape. The average MCP of DAM is greater than the average MCP of RTM for most of the hours. It is also evident that the average MCP of DAM and RTM are very close in 2020-21. However, in 2021-22, the difference in average MCP of RTM and DAM has increased.

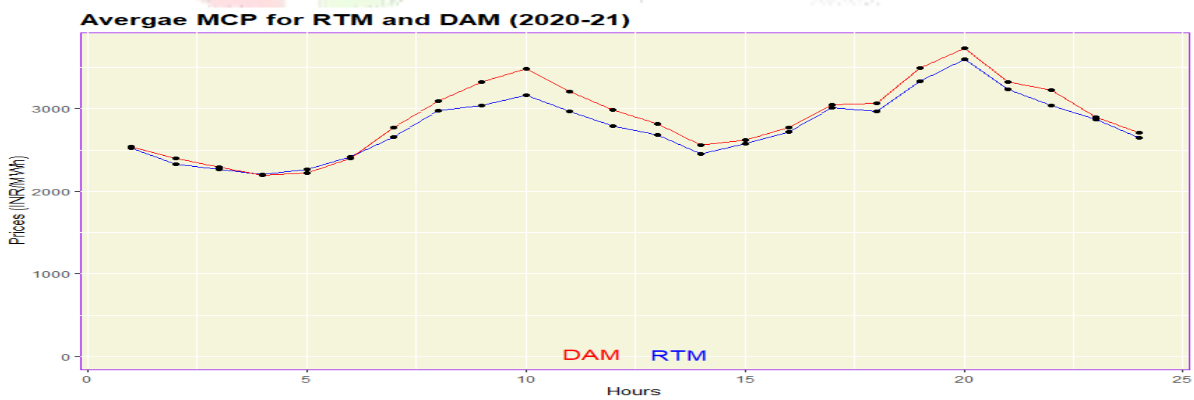

Fig: 1. Average Market Clearing Price of real time market and day ahead market in 2020-21

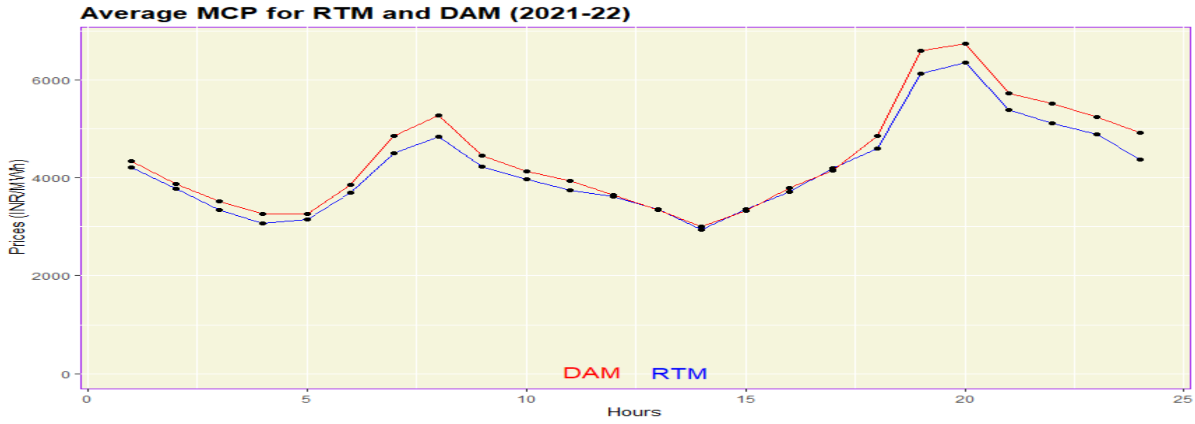

Fig: 2. Average Market Clearing Price of real time market and day ahead market in 2021-22

The Maximum MCP graph also show that both the markets move in tandem and thus, appear to follow a similar trend. The year 2020-21 shows that the maximum MCP in both the markets was different in many hours (fig 3) However, in 2021-22, its same for many hours. (fig 4)

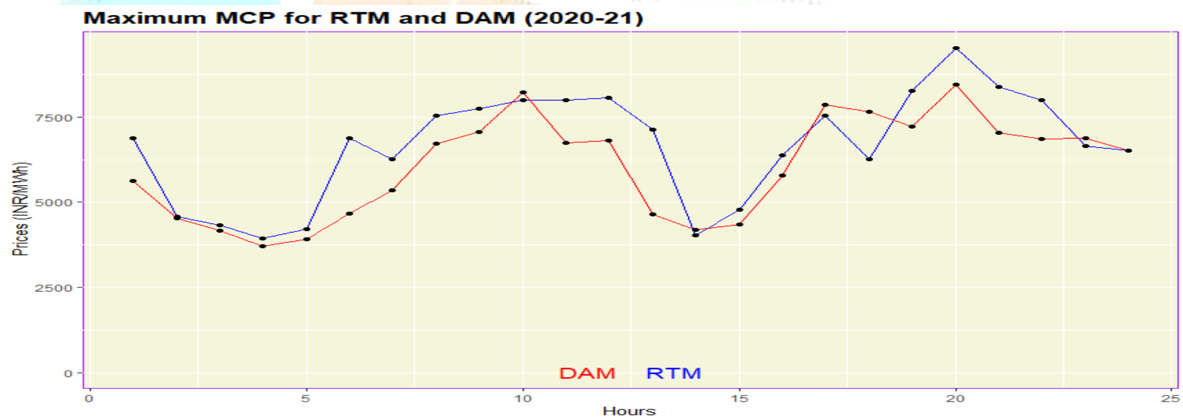

Fig: 3. Maximum Market Clearing Price of real time market and day ahead market in 2020-21

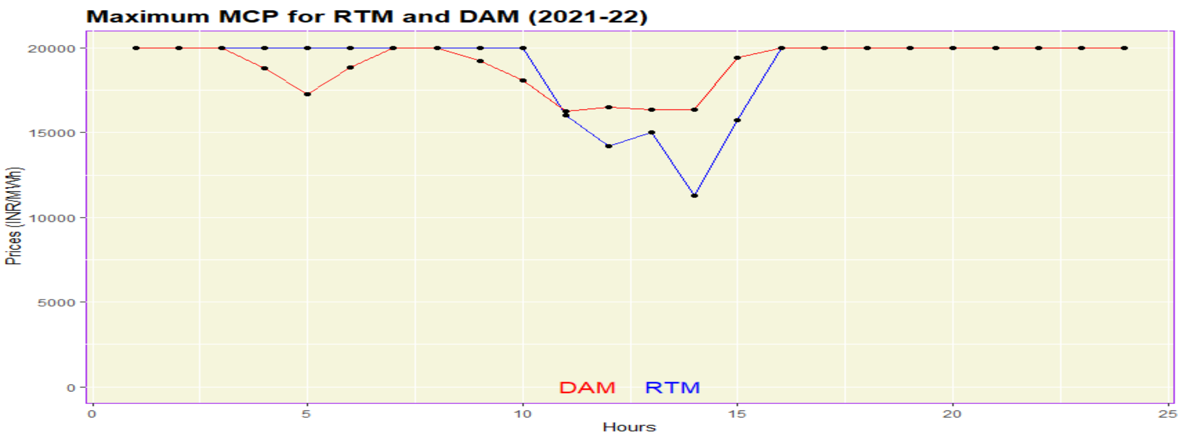

Fig: 4. Maximum Market Clearing Price of real time market and day ahead market in 2021-22

After a preliminary visual examination of the price series of both the markets, the paper adopts various econometrics models to study the relationship between both the markets. The objective of the paper is to understand the relationship between both the markets and assess the mark of efficiency reached in two-year periods. For comparative analysis of efficiency reached in both the markets the study period is divided into two parts: Period 1 is June 2020 to March 2021 and period 2 is April 2021 to March 2022.

Review of Literature

Various studies have measured the efficiency in different deregulated markets. De Vany and Wall (1999a) analyze the efficiency in western US electricity markets among the 11 interconnected regional markets using Johansen co-integration test. It concludes that markets were stable and highly integrated. Boreinstein et al. (2001) compare the market integration level between the day ahead and the real-time market of California. Their results show that significant price differences existed in the initial 32 months of operation, which reduced as time passed. Arciniegas et al. (2003) assess the efficiency across time and across US markets using Johansen co-integration and price convergence test. They conclude that as market matures, efficiency has increased. Girish et al. (2018) study the price discovery in Indian electricity day ahead spot prices and level of integration among different regions. They conclude that regional electricity prices are not highly integrated as compared to other developed nations. Longstaff and Wang (2004) study premiums and observe that premiums are positive during peak hours, which shifts to negative during afternoon hours in the PJM market. Zarnikau et al. (2014) investigate market price convergence in the Texas electricity market and conclude trading inefficiencies between DAM and RTM prices. Mhalas et al. (2021) investigate the relationship between day ahead and real-time markets using corelation analysis. They conclude that prices in both the markets are highly correlated. The present study is an extension of Mahals work where, we use more rigorous analytical tools such as co-integration to study the relationship and thus, assessing the efficiency between both the markets.

Research Objectives

The objective of this paper are:

To assess level of efficiency reached in Indian electricity market

To measure the cointegration between real time and day ahead electricity market in India

Data Analysis

The study has used hourly day ahead and real-time prices collected from IEX website. Two years are selected for the analysis from the launch of RTM market i.e., June 2020 – March 2021 and April 2021 – March 2022. 24 hourly price series are used for the analysis. For period 1 (June 2020 – March 2021) each hourly series has 304 observations. For period 2 (April 2021 – March 2022) each hourly series has 356 observations.

The Model

Price changes prediction is a criterion for evaluating the efficiency of financial markets. All the readily available information should be reflected in current prices so that no one can make abnormal gains using such information. The predictability of tomorrow's higher/lower prices cannot provide the opportunity of making super profits in electricity markets as electricity cannot be stored. However, when electricity markets allow participants to trade over different market segments such as day Ahead, Real Time, Ancillary, they may involve in wrong doing(Discussion paper) and can use of predictability of prices to make super profits[7].

Stationary series are easily predictable as they are independent of time with constant mean, variance and autocorrelation[12]

The study measures efficiency using three methods. Firstly, predictability of each hourly series is measured using stationarity. Secondly, it measures the co-integration relationship between RTM and DAM hourly series to check if expected return in both the markets are same or not. If two series re cointegrated, any shock in one market should also reflect in others, otherwise participants may benefit from arbitrage between both the markets.

Unit Root Test

First, we employ the Augmented Dickey-Fuller (Dickey and fuller, 1979) test (ADF test) to check the presence of unit root in all series. ADF test is estimated using the following equation:

$$\Delta P\mathrm{t} = \alpha + \beta_0 P_{t-1} + \sum_{t=1}^{L} \beta_1 \Delta P_{t-1} + e_t \quad (1)$$

Where,

$\Delta P\mathrm{t}$ = Change in Price at time t

α , β_0 , β_1 = Coefficient Parameters of regression to be estimated

P_{t-1} = price at time t -1

ΔP_{t-1} = with L lagged difference terms used for estimation of errors

e_t = Error term

Null hypothesis of ADF test is presence of unit root in the series. Maximum number of lags determined using Schwert's rule of thumb.

$$P_{max} = 12.\left(\frac{T}{100}\right)^{1/4}$$

Following the Schwert's formula, for 2020-21, maximum no. of lags are 16 and for 2021-22 are 17

The test is applied in R software using ur.df() function of urca package with constant as a deterministic regressor, initially taking the maximum lags and selecting the lags based on Aikaine Information Criterion (AIC). Residuals from the regression are also checked for serial correlation so that they are not serially correlated.

R excerpt >summary(ur.df(data$Hour1_RTM, type = “drift”, lags = 17, selectlags = “AIC”)).

Results of ADF test are presented in Table 2.

Other unit root test such as PP test, KPSS test gave contradictory results. We used ADF test with constant, and residuals are tested for serial correlation so that regression is not spurious.

In electricity markets, due to its non-storable nature, stationary series in one market do not lead to wrongdoing or arbitrage opportunities[10]. However, if stationarity is present in both the markets day ahead and real-time, this could lead to arbitrage opportunities[7.]

Table 2

Results of ADF unit root test for each hourly price series. An Aestrick (*) shows that null hypothesis of unit root is rejected at 99% confidence interval, ** shows that for a particular hour, both day ahead and real-time markets reject the null hypothesis of unit root

Hours	2020-21				2021-22			
	Real		Day Ahead		Real		Day Ahead	
1	-1.7368	10	1.0056	15	-2.3245	5	-2.3245	5
2	-1.4084	13	-0.9947	5	-2.7634	12	-2.8447	9
3	-2.171	8	-1.2945	4	-2.4259	10	-2.6773	10
4	-1.8803	9	-0.5771	9	-2.6607	5	-2.8249	10
5	-2.1868	9	-0.4285	14	-3.4687*	5	-2.5533	10
6	-3.0349	6	-1.0111	7	-2.1966	15	-2.4767	12
7	-2.2758	6	-1.0093	6	-1.595	16	-2.0844	9
8	-1.9073	11	-1.1595	14	-2.2087	8	-0.6927	16
9	-2.6205	6	-1.2912	16	-3.1403	7	-1.6235	15
10	-1.5698	13	-1.186	14	-3.1798	7	-2.535	10

11	-1.5503	15	-1.2621	12	-3.2406	6	-1.1548	15
12	-2.5293	6	-1.8834	7	-2.8303	6	-2.0315	15
13	-2.5434	6	-1.0056	13	-2.954	6	-1.9367	14
14	-2.2463	13	-0.872	13	-3.9557**	7	-3.6051**	7
15	-2.4147	13	-2.4025	7	-3.6602*	12	-3.3612	7
16	-2.9196	6	-1.7987	7	-4.535*	8	-2.9068	8
17	-1.0566	13	-0.7225	14	-2.6603	14	-1.7058	14
18	-1.709	13	-0.0512	13	-3.5616*	8	-2.6094	16
19	-1.8424	13	-1.3493	14	-2.2417	15	-2.1034	14
20	-2.2082	13	-1.1516	14	-2.1145	7	-2.3145	15
21	-3.1787	6	-1.3308	14	-2.1353	11	-2.4143	14
22	-3.0597	6	-0.7106	14	-2.5862	11	-2.8403	15
23	-2.5983	7	0.0105	9	-2.4729	6	3.2058	14
24	-1.2539	16	0.6722	9	-2.3421	11	-2.7987	10
Stationary hours in both day ahead and real time			0		1			

Cointegration Test

When two markets trade the same commodity, the expected return in both markets should grow at the same rate and follow the same trend. An arbitrage opportunity arises if the expected return in one market is higher or lower than the other market. In financial time series analysis, two series growing at the same rate and tracking each other are called cointegrated series. Johansen 2009 "Cointegration is a phenomenon that non-stationary processes can have linear combinations that are stationary". A series is integrated of order d means it has been differentiated d times to get it stationary[12]. Two cointegrated series should be integrated at the same order as different order integrated series can not be cointegrated.

Co-integration equation

$$P_{d,h} = \alpha + \beta P_{r,h} + \epsilon_h$$

Where,

$P_{d,h}$ = day ahead market price at hour h

$P_{r,h}$ = Real time market price at hour h

α & β = Cointegration Parameters

ϵ_h = error terms

To discover the relationship Johnsen co-integration test is used. Johansen test needs non-stationary series at level and stationarity at first difference. Results of ADF test series at first difference is given in table 3.

R excerpt > summary(ur.df(data$diff_Hour1_RTM, type = “drift”, lags = 17, selectlags = “AIC”))

Table 3: Results of ADF test with a first differenced series

Hours	**2020-21**				**2021-22**			
	Real	**Lags**	**Day Ahead**	**Lags**	**Real**	**Lags**	**Day Ahead**	**Lags**
1	-7.4909	13	-5.2292	13	-6.4005	9	-10.1729	4
2	-7.8273	12	-5.1022	13	-8.6417	6	-5.5556	8
3	-7.705	12	-8.6371	7	-8.8315	6	-6.4837	9
4	-10.3561	8	-9.2107	8	-12.5465	4	-7.1009	9
5	-9.9102	8	-5.8756	13	-13.2487	4	-7.3326	9
6	-5.9885	16	-10.1968	6	-6.1365	14	-5.8413	15
7	-9.9825	8	-5.0996	16	-5.9562	15	-8.5423	8
8	-9.1173	10	-5.8041	13	-8.4183	7	-6.5382	15
9	-8.6095	10	-4.1715	16	-6.2024	17	-7.1093	14
10	-8.4098	12	-7.8812	12	-11.5312	6	-7.8143	12
11	-7.1258	16	-8.0352	11	-7.0213	14	-7.6417	12
12	-6.4088	16	-6.1163	16	-13.5812	5	-6.7419	13
13	-6.7103	15	-8.4238	12	-13.2645	5	-6.626	13
14	-7.9942	12	-9.1754	12	-8.8802	6	-8.3452	7
15	-7.7424	12	-7.7174	12	-7.2553	14	-7.66	10
16	-7.3866	12	-6.9113	12	-7.9918	12	-8.334	7
17	-6.3859	15	-6.4904	12	-8.4516	12	-7.2335	11
18	-8.7484	12	-8.5908	12	-7.0706	12	-5.6937	14

19	-7.652	16	-8.531	12	-5.7897	14	-5.6748	13
20	-7.0323	16	-5.5301	15	-13.8438	5	-5.3107	13
21	-6.7672	14	-6.118	12	-6.566	10	-5.4116	13
22	-6.6792	14	-6.6287	12	-6.3072	10	-4.9534	15
23	-11.8723	6	-8.8428	8	-12.1922	5	-6.1037	12
24	-7.4337	14	-4.1067	14	-13.0991	5	-7.6935	6

All hourly time series are stationary at I(1). We move to measure some cointegrating relationships between the variables using the Johansen co-integration test.

Vector Autoregressive Model (VAR) is estimated for the Johansen test as shown below:

$$P_t = \Gamma_o + \Gamma_1 P_{t-1} + \Gamma_2 P_{t-2} + \cdots \Gamma_k P_{t-k} + \varepsilon_{t-k}$$

Optimal lag length is determined for the unrestricted VAR using VARselect function given a maximum lag length of 10 as data comprises only two variables. Output has optimal lag length as per AIC, HQ, SC, FPE. VAR model was estimated using lag length based on AIC criterion.

```
R excerpt > hour 1 = data$Hour1_RTM          #hour 1 RTM data is put into another variable
R excerpt > hour 1.1 = data$Hour1_DAM        # hour 1 DAM data is put into another variable
R excerpt > dset1= cbind(hour1, hour1.1)     #combined both the hours into another variable
R excerpr > VARselect(dset1)                 #selelct optimal lag length (default lag is 10)
R excerpt > summary(ca.jo(dset1, type = "trace", ecdet = "const", k = 5))
R excerpt > summary(ca.jo(dset1, type = "eigen", ecdet = "const", k = 5))
```

Table 4: Results of Johansen Cointegration Test. An X shows that series is not stationary. AN x denotes that no stationary combination could be formed

Hours	2020-21		2021-22	
	Trace Statistic	Eigen Statistic	Trace Statistic	Eigen Statistic
1	57.38	55.76	48.7658	46.96
2	30.88	29.34	30.94	24.93
3	60.56	57.32	30.46	28.03
4	53.54	49.62	23.89	17.75
5	60.58	56.44	X	X
6	27.35	25.03	21.09	14.91
7	31.68	29.21	27.66	22.23
8	33.07	30.55	23.73	21.16
9	31.43	29.16	x	x
10	30.44	28.32	47.32	38.08
11	26.87	22.50	29.00	22.29

12	28.68	24.06	x	x
13	31.96	27.70	49.31	40.48
14	23.86	19.12	X	X
15	29.55	23.46	X	X
16	34.80	31.34	X	X
17	27.73	25.72	57.56	48.73
18	25.74	23.23	X	X
19	40.13	36.07	39.21	33.52
20	38.57	35.76	33.70	30.01
21	37.28	34.59	38.52	33.91
22	38.55	37.32	41.92	36.16
23	27.59	26.60	25.98	19.09
24	31.75	29.41	51.23	44.69
Integrated hours	24		17	
Efficiency (%)	100%		71%	

Results and Discussion

Table 2 shows the result of the unit root for both markets. In electricity markets, stationary series in one market do not provide any opportunity to manipulate the market; therefore, hours of interest are those when the series is stationary in both markets. Stationary hours in both day and real time increased from 0 to 1 between 2021 and 2022. One reason could be that as the market grows, participants become more experienced and thus, able to take advantage of market imperfections.

Table 4 shows the efficiency measured by Johansen co-integration test. In 2020-21, the day ahead and real-time markets were cointegrated in all the hours. However, in 2021-22, cointegrated hours are reduced to 71%. The efficiency decreased in 2021-22 as compared to the previous year.

Conclusion

The paper assesses the efficiency reached by the Indian electricity market in the past two years of real-time market commencement. Results show that efficiency has decreased in the second year 2021-22. As apprehended in various reports, the multi markets with multi-settlement system could provide an opportunity trades to various market participants by switching between different markets. These opportunity trades leave the market inefficient. Contrary to the popular belief that efficiency increases with maturity, efficiency has decreased in Indian market.

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