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When index dissemination goes wrong: How fast can traders add and multiply?

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Abstract

This paper studies an episode of dissemination of wrong stock index values in real time due to a software bug in the Indian Nifty index futures market on the morning of January 18, 2006.

The episode provides an opportunity to test various models of cognitive biases and bounded rationality highlighted in behavioural finance. The paper provides strong evidence against cognitive biases like "anchoring and adjustment" (Tversky and Kahneman, 1974) that one might expect under such situations even though the cognitive task involved is quite simple. The futures market tracked the true Nifty index which it could not see while completely ignoring the wrong Nifty index that it could see.

However, the paper demonstrates that market efficiency failed in more subtle ways. There is evidence of a partial breakdown of price discovery in the futures markets and a weakening of the bonds linking futures and cash markets.

This evidence is consistent with the centrality of "market devices" as argued in "actor network theory" in economic sociology (Muniesa, Millo and Callon, 2007 and Preda, 2006). Well functioning markets today depend critically on a whole set of information and communication technologies. Any failures in these material, socio-technical aspects of markets can make markets quite fragile even if behavioural biases are largely absent.

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Acknowledgements

I have benefitted from discussions with several market participants, analysts and experts on the episode studied in this paper. In particular, I would like to acknowledge the following persons who contributed significantly to my understanding of the issues involved:

- Mr. Vineet Bhatnagar, Managing Director and CEO, MF Global-Sify Securities India Pvt. Ltd., a large derivative broking firm in India, provided me with valuable insights based on his ringside view of the events studied in the paper, and clarified several of my doubts about the behaviour of market participants on that day.

- Mr. Ashish Chauhan, currently Deputy Chief Executive Officer of the Bombay Stock Exchange, was at the time of the event the Group Chief Information Officer of the Reliance Group and was intimately involved in the demerger of the Reliance group. It was an error in correctly accounting for this demerger that led to the wrong dissemination of the Nifty on January 16, 2006. Mr. Chauhan provided me a very important corporate perspective on the event, and also shared his knowledge of how market participants and other stakeholders reacted to the error.

- Ms. Latha Venkatesh, Banking Editor, CNBC TV-18 – one of India's leading business television channels – provided me with archival videos of the live commentary on this channel of the first hour of trading on January 16, 2006. I would like to thank CNBC-TV18 for these videos which were very helpful in reconstructing how analysts and participants processed the information relating to the error in real time. Live telecasts are perhaps the only source that is completely free from hindsight bias.

- My colleague, Prof. Joshy Jacob, at the Indian Institute of Management, provided valuable comments on an initial draft of this paper and suggested several ways of improving it.

Needless to say, any errors in interpretation and analysis are my own.

When index dissemination goes wrong: How fast can traders add and multiply[2]?

Jayanth R. Varma (jrvarma@iimahd.ernet.in)

The wrong dissemination episode of January 18, 2006

As part of a settlement process mutually agreed upon after a year-long ownership dispute between the Ambani brothers, a demerger scheme was carried out in 2006 to hive off the interests of Reliance Industries Limited in power, telecom and finance to a new group started by the younger brother Anil Ambani. After demerger, Reliance Industries under Mukesh Ambani, the elder brother, was focused on petrochemicals, refinery and oil and gas exploration. Reliance Industries Limited was part of the Nifty index which is the dominant index in India's index futures market.

On January 18, 2006, the National Stock Exchange (NSE) organized an hour-long special trading session between 8 am and 9 am to value the demerged Reliance Industries. Based on the price discovered in the special session, adjustments were suitably carried out to the base index value to compute the index value so as to give effect to the demerger. The market then opened as per normal market timings.

The NSE describes what happened thereafter as follows (National Stock Exchange, 2006):

> "The market opened and the correct adjusted index value of NIFTY was also displayed to the market at the opening trade. The activity of NIFTY index computation was closely monitored after market opening and it was seen that the first few NIFTY index values were computed correctly taking into account the adjusted base index value. However once the first trade in Reliance Industries Ltd. was executed, it was observed that the NIFTY Index reflected incorrect value. The problem was analysed and found that due to memory initialization failure the last traded price being reckoned for index computation purpose was carrying an incorrect value. This resulted in a wrong NIFTY index value being displayed. The problem was identified and changes were carried out to reflect the correct value of the NIFTY index. The NIFTY index dissemination was stopped at 10.30 am and the correct display of NIFTY index value was made available to the market from 10.56 am onwards. The other indices remained unaffected."

The NSE went on to assert: "The prices of NIFTY contracts continued to be at market during the period when the NIFTY index value was incorrectly disseminated as can be seen from the graph enclosed."

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[2] The second part of the title is inspired by section 4.3.3 on "How fast can we multiply?" in Donald Knuth's celebrated book: **Knuth, D. E. (1998)** *The Art of Computer Programming, Volume 2: Seminumerical Algorithms*, Addison Wesley.

Figure 1: Graph of wrongly disseminated Nifty Index values and Futures prices published by NSE to support its claim that the prices of Nifty futures contracts continued to be at market when the Nifty index value was incorrectly disseminated.

The graph does provide tentative support for the claim that the wrong index values did not fool the market. But a graph is useless for any rigorous analysis of what happened in the interconnected market for cash equities and index futures.

Data and sampling

To carry out a proper econometric analysis, I worked with intra-day (tick by tick) values of the Nifty index and futures contract extracted from the data disks published by the NSE. I was not able to obtain the data on the wrong values that were disseminated on January 18, 2006: the NSE stated in an email that the wrong data does not appear to have been stored. I obtained values for this series by digitizing[3] the graph in Figure 1.

[3] I used the open source Engauge Digitizer available at http://digitizer.sourgeforge.net

For the purpose of econometric analysis, all the time series were sampled at a frequency of one minute by averaging the values during each minute. The resulting data for all the three series obtained from these two sources is plotted in Figure 2. The intra-minute spikes in the wrong Nifty around 9:55 am and 10:00 am in Figure 1 are reduced by one-minute averaging (though the digitization process itself preserved these spikes). Apart from these intra-minute spikes, the plot of the wrong Nifty in Figure 2 closely follows the plot of the same series in Figure 1.

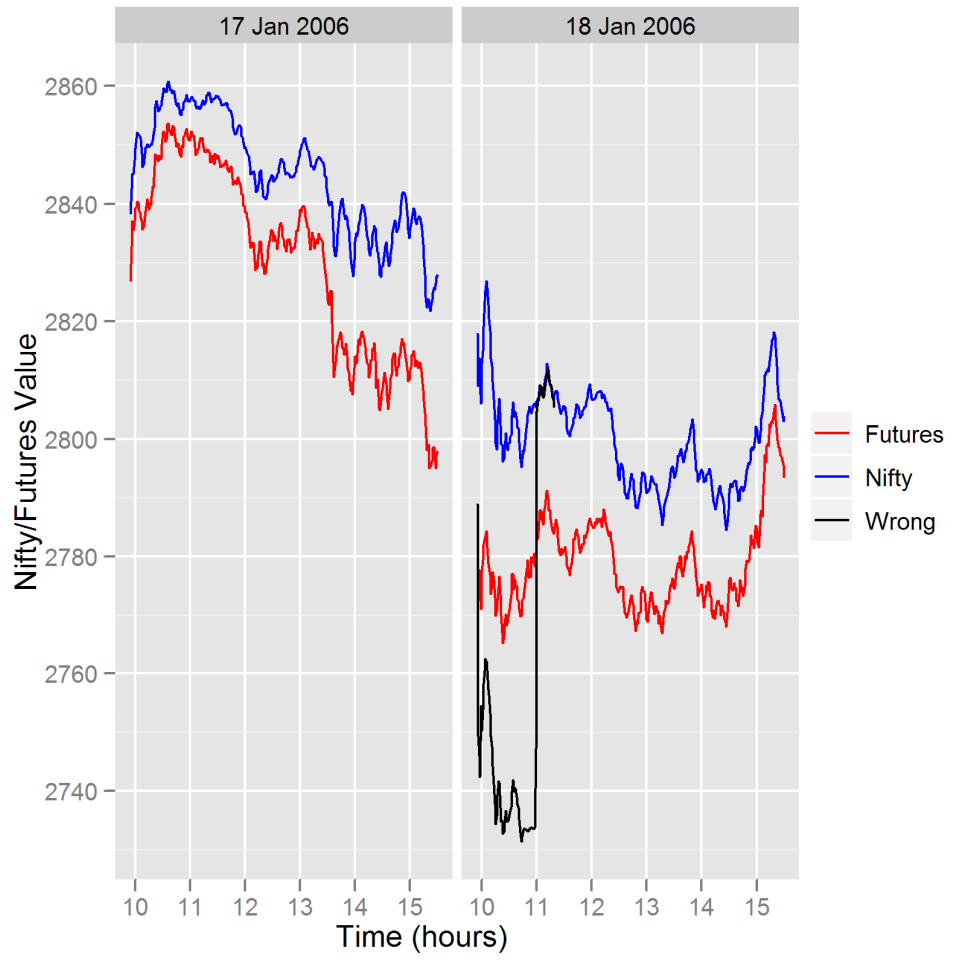

Figure 2: Futures price, Nifty index values on 17 and 18 January and wrong index values disseminated on 18 January. The plot is based on data sampled (by averaging) at one minute frequency.

What happened in the first one minute?

Before turning to the econometrics using sampled data, it is useful to look at the full tick by tick data during the first one minute of trading on January 18, 2006. In the space of about half a minute, the disseminated wrong Nifty plummeted almost 90 points from its opening level of around 2829 to the first minute low of around 2742. During this period, the difference between the open and the first minute low for the

true Nifty and the futures price was well below one-tenth of the drop in the wrong Nifty – a mere 5 or 6 points.

Instrument	No of trades	Open	High	Low	Close	Mean
True Nifty	1428	2816.00	2839.85	2809.90	2812.35	2817.91
Nifty futures	609	2770.00	2781.00	2765.25	2769.00	2769.47

This implies that there was probably not even a single trade of the Nifty futures that was swayed by the wrong Nifty values. For a contract with a traded value of Rs 899 million during this first minute at an average of 10 trades a second, this is surprisingly strong evidence in favour of market efficiency.

It is difficult to believe that the market took only a fraction of a second to figure out that the disseminated Nifty values were wrong. It is more plausible that the market took a few seconds to figure this out, but in the absence of algorithmic high frequency trading in the Indian market at that time, it would have taken several seconds for traders to place new orders into the system. Within these few seconds, they might have figured out the error.

The first five minutes

I watched archival videos of the live commentary on the market from one of India's leading business channels – CNBC TV18 – to get a better understanding of what happened in the first five minutes of trading.

Just before trading began in the Indian markets on January 18, 2006, the channel presented news from other Asian markets. Japan (Nikkei) was down 3.26%, Singapore (Strait Times) was down 0.72%, Korea (KOSPI) was down 3.74% and Taiwan was down 3.19%. As the anchor[4] said "I don't want to spook you early in the morning, but that is reality staring at you. Asian markets are taking it in the neck." The Indian market was also expected to open lower, but losses were expected to be much lower than in the exporting powerhouses of East Asia. There were also some good corporate results to perk up the market.

It is common for the Indian market to move significantly at the open in response to overnight news flow from the US and from Asian markets. The standard deviation of price changes at the open (from the previous day's close) during the one year preceding January 18, 2006 was 0.24%. This was dwarfed by the standard deviation of 1.04% for price changes from the open to the same day's close. For another comparison, on the previous day (January 17, 2006), the standard deviation of price changes during one minute of trading was 0.04%.

At the opening bell at 9:55 am on January 18, 2006, the prices of actively traded stocks started flashing across the screen on CNBC-TV18. About half a minute after

[4] The anchor was Mr. Udayan Mukherjee, Managing Editor of CNBC-TV18.

the opening bell, the indices started appearing on the screen. First up was the 30 share BSE Sensex which like the Dow Jones Index in the US is widely followed though it is not the index on which the main derivative market is based.

The screen shows "Sensex 9293.80 ▼20.33 -0.22%" and the anchor explains the action: "Sensex has opened 20 odd points down. Something tells me it should have fallen more." Next comes the Nifty; the screen shows "Nifty 2757.60 ▼71.50 -2.53%." The anchor is shocked: "Nifty has fallen 71 points at 2757. Two and a half percent! What is happening there? There is a disconnect there for sure."

The channel then turns to some of the leading stocks (most are down modestly) and then to the Sensex which by now has slipped 42 points. The screen shows "Sensex 9271.51 ▼42.62 -0.46%." It is now almost one minute after the opening bell, and the anchor returns to the unexplained fall in the Nifty:

> "What could have knocked off? Is it an error in calculation? I imagine it is. Because Nifty has fallen 80 points, that is three percent while Sensex is down half a percent, and nothing seems to have collapsed that much for the Nifty. I don't know. Reliance is at 708, that has not fallen so much and it is adjusted. So it would not have affected the index. Is it a wrong calculation on the screen out here? The Sensex is down 41, that is more like it. And the Nifty is showing you 87 points down. I imagine that could be a bit of an error out there in calculation."

The anchor then points out that a few stocks have fallen a couple of percentage points, but there is nothing to suggest a 3% fall in the index. About one and a half minutes after the opening bell (or about a minute after the first Nifty quote appeared on the TV screen) the anchor concludes: "I don't know what is happening there."

During the next half a minute, the anchor keeps coming back to the Nifty problem:

> "Still intrigued by the three percent fall in the Nifty. I don't know whether the wires are making some kind of error or is this coming from the exchanges. We will run a check on that very soon and tell you."

> "There is nothing in the Nifty to suggest a three percent fall unless they are calculating the entire Reliance fall and that is getting translated into the Nifty which is a possibility and which would be an error in this case, but I am not too sure about that. We will get a check going."

About three minutes and twenty seconds after the opening bell, the channel starts flashing its estimate of the Nifty (2829.10) on the screen. During the space of one minute, the channel flashes this "alert" four times with the same value of 2829.10. Clearly, the channel has been able to make some kind of computation of the Nifty index, but has not been able to keep updating its computation in real time.

Nearly five minutes after the opening bell, the anchor warns the viewers not to go by the official Nifty numbers: "But the Nifty is not down too much. In fact, the current rate is closer to 2830 – 2820 types and not the 2742 that you see on the screen at all." The anchor's caution in giving a range instead of a single number is very prudent – according to the corrected index published later by the exchange, the correct value of the Nifty at that time was closer to 2810.

About five and a half minutes after the opening bell, the channel interviews a trader who says that on his trading screen also both the Nifty and the Defty (the US dollar version of the Nifty) are showing the wrong numbers and conjectures that the calculation mistake is related to the Reliance demerger.

After that, CNBC TV-18 chose to focus on the Sensex value as the indicator of the broader market, and more or less ignored the Nifty apart from an occasional flash about a calculation error in the Nifty. Those trading Nifty futures of course did not have the option of ignoring the Nifty in this manner.

What determined futures prices on the 18th morning?

I have already presented the analysis based on tick by tick data to show the ***level*** of the wrong Nifty index had no impact on the market. We now ask whether the market did look at the ***changes*** in the disseminated Nifty rather than its absolute level after figuring out that the level of the disseminated Nifty was wrong.

Using the minute-by minute data[5], I regress the Nifty futures returns[6] on returns in the wrong Nifty and returns in the true Nifty to obtain the following result:

Table 1: Regression of Futures returns on wrong Nifty returns and true Nifty returns during the period when true Nifty was not available. The market appears to track the true Nifty which it could not see while ignoring the wrong Nifty that it could see.

Variable	Coefficient	Std. Error	t value	Pr(>|t|)	
Constant	3.875e-05	6.158e-05	0.629	0.532	
True Nifty Returns	7.163e-01	7.800e-02	9.183	5.67e-13	***
Wrong Nifty Returns	-6.048e-02	5.955e-02	-1.016	0.314	
R-squared: 0.6079, F-statistic: 45.74 on 2 and 59 DF, p-value: 1.009e-12					

Clearly, the futures returns are strongly related to the returns on the true Nifty – the coefficient value of 0.7163 is economically quite large (not that far from unity) and the t-statistic of 9.183 is highly significant. However the futures market completely ignored what was happening to the disseminated (wrong) Nifty values – the coefficient value of -0.0605 is of the wrong sign, is economically quite small and is also statistically insignificant.

This is a surprisingly strong finding in favour of market efficiency. The futures market appears to track the true Nifty which it could not see while ignoring the wrong Nifty that it could see.

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[5] To avoid the results being distorted by the huge negative return in the wrong Nifty at the beginning of the day, I drop the first two minutes of data in all my analysis. This is simpler and probably more effective than using a bounded influence regression estimate.

[6] An additional reason for carrying out the regression using returns and not levels is that as discussed later in the paper, I am not able to reject the hypothesis of a unit root in the futures prices and in the index.

Of course the regression tells us nothing about the direction of causality:

- The futures market could have been estimating the true Nifty values without the benefit of the real time feed.

- The cash market might have been following the movement in the futures market. Bhatia (2007) provides evidence that the Nifty futures market leads the cash market.

Anchoring and adjustment

Tversky and Kahneman (1974) describe the phenomenon of anchoring and adjustment as follows:

> "In many situations, people make estimates by starting from an initial value that is adjusted to yield the final answer. The initial value, or starting point, may be suggested by the formulation of the problem, or it may be the result of a partial computation. In either case, adjustments are typically insufficient. That is, different starting points yield different estimates, which are biased toward the initial values."

Tversky and Kahneman (1974) point out that this phenomenon is observed even when the initial anchor is a random number obtained by spinning a wheel. It is natural then to assume that the wrongly disseminated Nifty index which was so salient would have served as an initial anchor. With insufficient adjustment, clearly it should have had some impact on the price.

The empirical evidence strongly rejects the theory of anchoring and adjustment. The disseminated wrong Nifty had no impact on futures prices either in terms of levels or in terms of returns. The evidence is strongly in favour of an efficient market and strongly against behavioural biases like anchoring and adjustment[7].

The data lends support to the view that some of the behavioural biases that are observed in laboratory setting do not occur in the context of structured and scaffolded decision situations that prevail in market settings. For example, Clarke (1997) argues: "traditional economic theory (invoking the substantive rationality paradigm) succeeds wherever individual choice is strongly constrained by social and institutional scaffolding that has itself evolved subject to selective pressures to maximize rewards. Outside such highly constrained settings, genuine individual thought plays a greater role, and the psychological irrealism of the substantive rationality model takes its toll."

More stringent tests of market efficiency

What I have shown is that on the morning of January 18, the market passed some of the basic tests of market efficiency and avoided some of the pitfalls that behavioural finance warns us against. But the efficient market hypothesis (EMH) makes much

[7] We could also perhaps interpret the evidence as being against the availability heuristic.

stronger demands on the market. The semi-strong form of the EMH asserts that market prices should reflect all published information.

Though the true Nifty was not being disseminated, the prices of the underlying stocks were being disseminated. The composition of the index and the constituent weights were also publicly available. Theoretically, therefore, the true Nifty could have been computed by any market participant with fairly rudimentary software. It is fairly straightforward[8] to design a spreadsheet that takes in real time price feeds of individual stocks and computes the index.

Strict standards of market efficiency would require the market to function as effectively without the true Nifty feed as it does with it. A quick glance at Figure 3 shows that this was not the case. It is visually evident that the relationship between true Nifty and Futures was much weaker when wrong Nifty was disseminated. The trend line through the scatter plot is much flatter during the period as compared to the approximately 45° line when the true Nifty was available.

[8] I do not intend the term "straightforward" to suggest that trading-room-ready software could have been put in place very quickly. It is possible that starting from scratch, traders might not have been able to complete the development, complete testing and integration of this software during the one hour or so when the wrong Nifty was being disseminated.

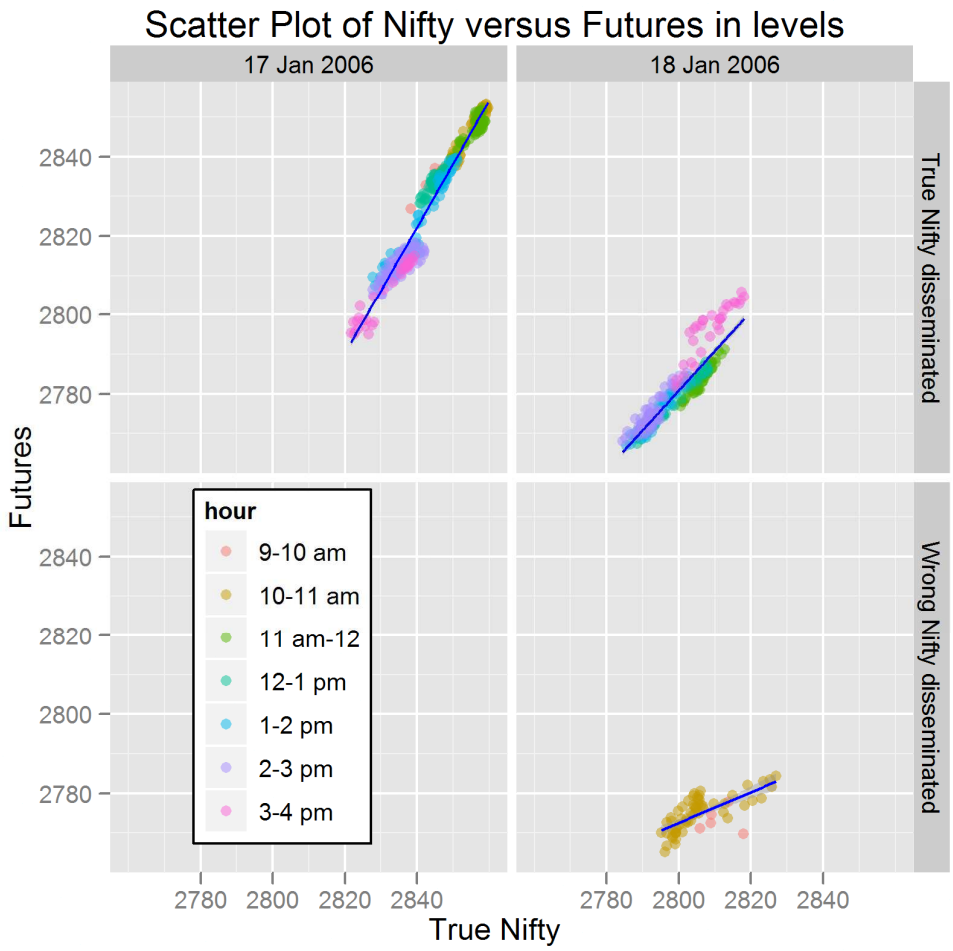

Figure 3: Relationship between true Nifty and Futures was much weaker when wrong Nifty was disseminated. The relationship does not appear to be different between the two days or between different times of the day.

The evidence is visually compelling, and would evidently be statistically highly significant[9], but there is a serious econometric issue about stationarity and co-integration to be addressed. A regression in levels between the futures price and the Nifty index is permissible only if the two variables are co-integrated. Bhatia (2007) provides evidence of co-integration between the futures and the index, but in the shorter data that I am using here, I am not able to establish co-integration:

[9] The Chow test results are: F-statistic: 213.17 on 2 and 666 DF, p-value: < 2.2e-16

- It is not possible to reject the hypothesis of a unit root in the difference[10] between the futures price and the Nifty index at even the 10% level using either the ADF or the PP test.

- The above test assumes a particular form (1, -1) for the co-integrating vector. I therefore tested for a general co-integrating vector using the Engle-Granger two step procedure. Again it is not possible to reject the hypothesis of a unit root in the first stage residuals at even the 10% level.

In the absence of co-integration, it is necessary to carry out the analysis in terms of differences or percentage changes[11]. A visual picture is provided in Figure 4 where it can be seen that the slope of the scatter diagram is somewhat flatter when the true Nifty is not available.

More importantly, the contour plot of the two dimensional density estimate that is superimposed on the scatter diagram is very informative. When the true Nifty is not available, the innermost contour lines are almost circular indicating a near absence of a relationship between the Nifty and the futures when the changes in the true Nifty are small. It is only the outer contour lines that are elongated in the direction implying that it is only when there are large changes in the true Nifty that the relationship becomes somewhat stronger.

This visual impression of an altered relation between the futures and the true index is confirmed by the regression results reported in Table 2. I regressed the returns in the futures on the returns in the true Nifty index separately for the periods when the true Nifty was disseminated and when it was not. I then tested for equality of the slopes using the Chow test.

[10] The results are similar if the test is based on the percentage difference between the futures price and the index.

[11] The returns are indeed stationary. The hypothesis of a unit root is comfortably rejected at the 1% level in Nifty returns (PP-test statistic = -11.9556; ADF test statistic = -11.9556) and in futures returns (PP-test statistic = -17.9427; ADF test statistic = -15.3825).

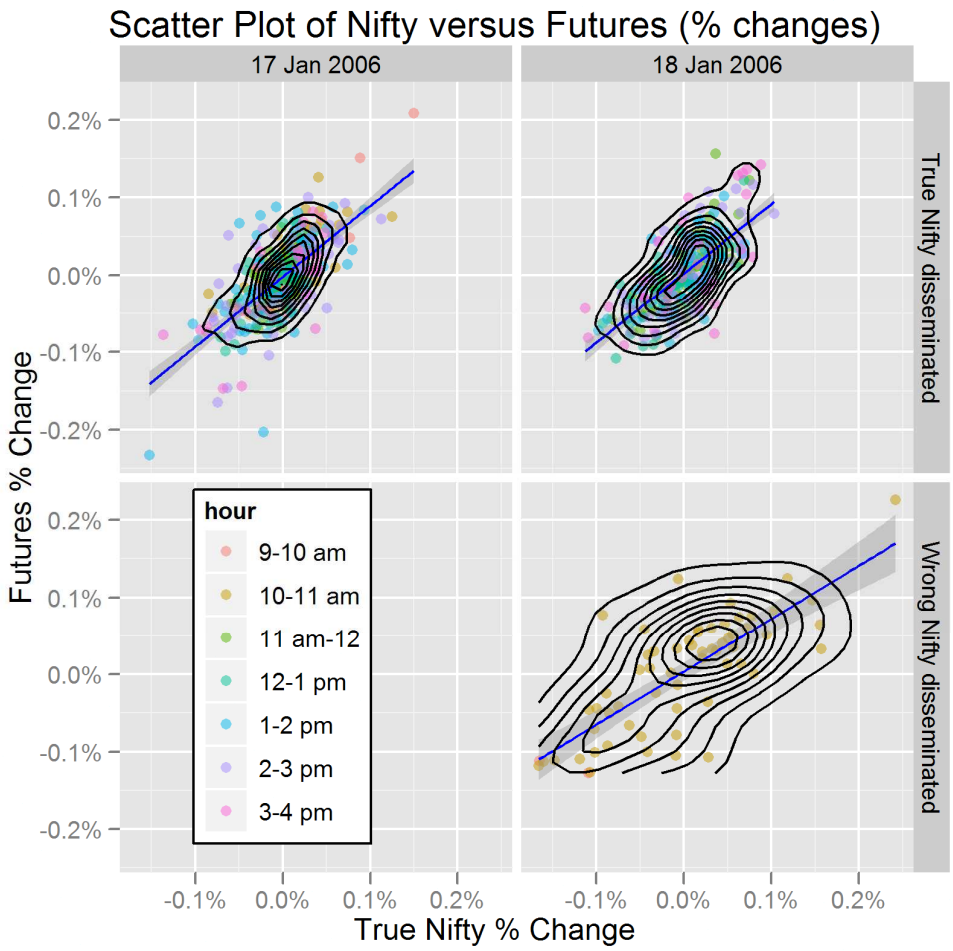

Figure 4: The relationship between futures returns and Nifty returns is also weaker when the wrong Nifty was disseminated

Table 2: The regression relationship between Futures returns and true Nifty returns changed when the true Nifty was not available.

A. During the period when true Nifty was available					
Variable	Coefficient	Std. Error	t value	Pr(>|t|)	
Constant	-1.975e-06	1.460e-05	-0.135	0.892	
True Nifty Returns	9.057e-01	3.816e-02	23.736	<2e-16	***
R-squared: 0.4826, F-statistic: 563.4 on 1 and 604 DF, p-value: < 2.2e-16					
B. During the period when true Nifty was not available					
Variable	Coefficient	Std. Error	t value	Pr(>|t|)	
Constant	3.683e-05	6.156e-05	0.598	0.552	
True Nifty Returns	6.861e-01	7.216e-02	9.508	1.39e-13	***
R-squared: 0.6011, F-statistic: 90.41 on 1 and 60 DF, p-value: 1.391e-13					
Chow test for a change in slopes: F-statistic: 5.6227 on 2 and 664 DF, p-value: 0.003789					

The relationship between the futures and true Nifty returns is significantly different when the true Nifty is not available. The coefficient is close to unity (0.9057) when the true Nifty is disseminated but drops sharply to 0.6861 when the wrong Nifty is disseminated. The Chow test shows that the difference in slopes is significant at the 1% level.

At the same time, the squared correlation is significantly higher when the wrong Nifty is disseminated. This apparently conflicting result is of course explained by the sharp differences in standard deviations:

Period	Standard Deviation of Nifty Returns (x 10,000)	Standard Deviation of Futures Returns (x 10,000)
True Nifty available	3.83	4.99
True Nifty not available	8.59	7.60
Ratio between two periods	2.24	1.52

It is tempting to imagine that the higher volatility is due only to the non availability of the Nifty. But this would be incorrect to for several reasons:

- Volatility is known to have a strong intra-day pattern (it is typically higher in the beginning of the day).

- The wrong dissemination happened on an unusual day where the market was trying to digest the implications of the price discovery that had taken place in the special session of the demerger of a large index constituent.

I therefore prefer to focus on the change in the regression slope which I find deeply troubling. Normally, one would expect a coefficient close to unity between the index returns and the futures returns. The fact that the slope dropped well below unity when the true Nifty was not available is suggestive of a break down of price discovery.

To investigate the matter more closely, I examined the response of futures prices to lagged changes in the percentage basis[12]. Essentially the question that I am asking is: if the gap between the index and the futures widens over this minute, does this widening reverse over the next minute by an offsetting move in the index[13]. It may be seen from Figure 5, that when the true Nifty is available, changes in the spot-futures basis tend to be reversed by an offsetting move in the index in the next minute. This does not happen when the wrong Nifty is disseminated (in fact, the scatter diagram has the wrong slope). This is indicative of a major break down of price discovery in the markets during this period.

[12] The spot-futures basis is the difference between the index and the index futures. I focus on the basis in percentage terms.

[13] The reversal could happen through a move in either the futures or in the index. Since futures are known to contribute more to price discovery, one would expect the index to move to correct the basis. This is confirmed by regression results discussed later.

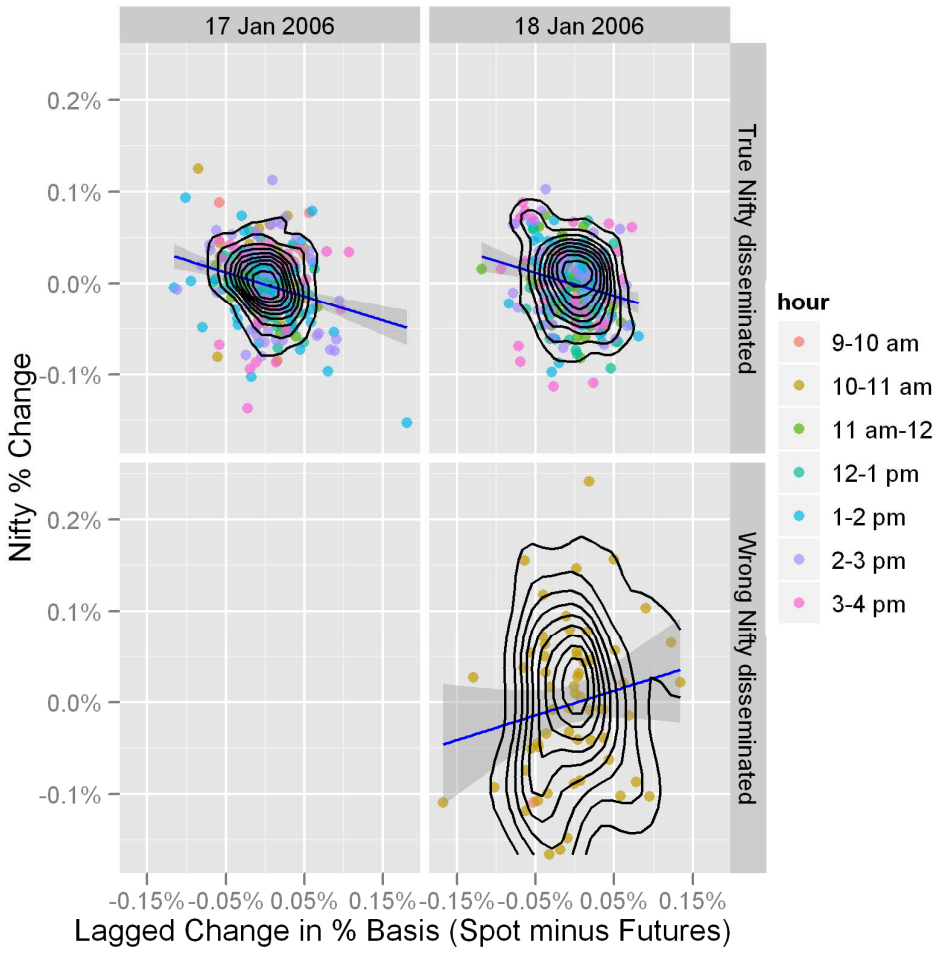

Figure 5: When the true Nifty is available, the Nifty moves to offset changes in the previous minute in the spot futures basis. This does not happen when the true Nifty is not available.

To test this, statistically, I ran the regression reported in Table 3 where Nifty returns are regressed on futures returns and on changes in the lagged percentage basis. When the true index is available, the Nifty does offset lagged changes in the basis – the coefficient is negative and highly significant. When the wrong Nifty was disseminated, the coefficient is of the wrong sign and is not statistically significant.

Table 3: The index moves to offset changes in the lagged basis only when the true index is available

Variable	Coefficient	Std. Error	t value	Pr(>|t|)	
A. During the period when true Nifty was available					
Constant	-3.377e-06	1.100e-05	-0.307	0.759	
Futures Returns	5.101e-01	2.264e-02	22.526	<2e-16	***
Lagged changes in percentage basis	-1.500e-01	3.130e-02	-4.792	2.08e-06	***
B. During the period when true Nifty was not available					
Constant	-2.993e-05	6.909e-05	-0.433	0.6664	
Futures Returns	8.477e-01	9.229e-02	9.185	6.57e-13	***
Lagged changes in percentage basis	2.127e-01	1.265e-01	1.681	0.0981	.

In regressions not reported here, futures returns were regressed on futures returns and on changes in the lagged percentage basis. In both time periods, the coefficient of the lagged change in the basis was not significant.

The natural conclusion is that under normal conditions, significant price discovery takes place in the futures market, and the cash market adjusts with a lag. However, when the true Nifty is not available, the futures market is not able to perform this function. Price discovery is impeded in the futures market.

Discussion and Conclusion

Even in the absence of a true index price feed, the market did not exhibit the stupidities that behavioural finance models of anchoring and adjustment might have predicted. But the absence of the true price feed did make the market much less smart than normal.

The good news is that even during the entire period of systems failure, the futures market tracked the true Nifty index which it could not see while completely ignoring the wrong Nifty index that it could see. The tick by tick data shows that the futures market was not even momentarily deceived by the wrong Nifty index that was disseminated. It is true that the cognitive task involved in index computation is quite simple, yet the evidence that markets can overcome cognitive biases is encouraging.

However, price discovery failed in more subtle ways that are at variance with strict definitions of market efficiency. Under extreme standards of market efficiency, the index disseminated in real time by the exchange adds no new information as long as the prices of the underlying stocks are being disseminated and the composition of the index and the constituent weights are publicly available. According to strict interpretation of the semi-strong form of market efficiency, a failure of the real time index price feed should make no difference.

It is true that the true Nifty could have been computed by any market participant using any standard spreadsheet software that has the capability to take in real time price feeds of individual stocks. If one imagines a world in which index futures are traded but nobody disseminates the index in real time, most market participants would build,

test and deploy their own software to perform this computation. But that is not the world in which we live. In the real world, the index is disseminated in real time by an authoritative source and therefore market participants have little incentive to build and deploy highly robust and reliable software to perform index computation.

From my conversations with market participants, I learnt that large market participants did have spreadsheets to compute the Nifty index, but there was unanimity that the confidence that they had in these spreadsheets was quite limited. The typical response was that such an excel sheet serves well as an information but traders will surely be hesitant to include its output for example for proprietary trades or even into algorithmic trading for their large institutional clients. Data feed from an exchange is considered as reliable by proprietary trading brokers and by algorithmic and high frequency trading clients.

The video of the CNBC-TV18 live market commentary in the opening minutes of trading also leads to the same conclusion. The channel is able to say quite categorically that the official Nifty is wrong, but it is rightly much less confident about its own estimate: "But the Nifty is not down too much. In fact, the current rate is closer to 2830 – 2820 types and not the 2742 that you see on the screen at all." As already mentioned, with hindsight, we know that the correct Nifty at the time was closer to 2810.

When the disseminated index has an error of about 2½%, even a crude computation with an accuracy of ¼% or even ½% is quite adequate to convince oneself that the disseminated index is wrong. However a ¼% accuracy might not provide enough confidence to trade the index futures or arbitrage it against the cash market.

The initial response of market participants to the wrong Nifty price feed might well have been that it would be corrected very soon. As several tens of minutes passed without correction, some large participants might have thought of strengthening their pre-existing index computation capabilities, performing some quick robustness tests, and integrating the enhanced software into their core trading operations. Even if they then set about doing this in right earnest, they might not have completed the development of trading-room-ready software[14] before the true Nifty dissemination was restored.

More importantly, even if every market participant did succeed in calculating the true index value with extremely high degree of reliability and confidence, these individual computations do not restore the situation that prevailed when there was a true index price feed. The key point is that in the presence of a price feed, the index value is

[14] The algorithm for the intra day index computation is actually quite trivial – it boils down to calculating a weighted average. This is because changes to the base to reflect corporate actions are not carried out intra-day. However, on January 18, 2006, the real time index dissemination failed at the beginning of the day. Moreover, the special session that had taken place before the market open (for the price discovery of the demerged Reliance Industries) amounted to a corporate action that had to be accounted for.

"common knowledge[15]". Everybody knows that everybody is seeing that same index value on the trading screen.

Even if every participant succeeded in replicating the index computation on the morning of January 18, 2006, the index value would not have been common knowledge[16]. Each participant would have known the index value, but nobody might have known that all others knew it as well. Had the disruption lasted several hours or several days, then it might gradually have become common knowledge as participants talked to each other or as the news media reported the developments.

It is well known that arbitrage sometimes depends on common knowledge and not just knowledge by each participant individually. For example, Abreu and Brunnermeier (2002) describe a situation where mispricing is not arbitraged away for a long time because "at no point in time is the mispricing common knowledge among the arbitrageurs. It might be the case that all arbitrageurs know of the mispricing, and all arbitrageurs know that all know that the price is too high or too low, but it is never the case that all arbitrageurs know that everybody knows that everybody knows and so on ad infinitum."

Muniesa, Millo and Callon (2007) rightly argue that "Calculation is … the concrete result of social and technical arrangements." What was seen on January 18, 2006 was a failure of part of these technical arrangements. Even if an alternate set of technical arrangements were put in place, the market's "calculation" of the correct futures price might have been impeded until the technical arrangements were embedded in a set of social arrangements that produced common knowledge of the true index value.

The evidence presented in this paper of the breakdown of price discovery in the futures markets points to the centrality of "market devices" as argued in actor network theory (Muniesa, Millo and Callon, 2007 and Preda, 2006). Well functioning markets today depend critically on a whole set of information and communication technologies. Any failures in these material, socio-technical aspects of markets can make financial markets quite fragile even if behavioural biases are largely absent.

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[15] The notion of "common knowledge" was introduced into statistics by Aumann (1976) who explained the concept thus: "Call the two people l and 2. When we say that an event is 'common knowledge,' we mean more than just that both 1 and 2 know it; we require also that 1 knows that 2 knows it, 2 knows that l knows it, l knows that 2 knows that l knows it, and so on."

[16] This argument is also relevant in the more realistic case where many participants succeed in computing an approximate value of the true index by using real time prices of a few important stocks. Index arbitrageurs who are accustomed to perform cash-futures arbitrage using a tracking portfolio consisting of a basket of large and liquid stocks might have found this particularly easy to do.

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