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Bond Market Prediction using an Ensemble of Neural Networks

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ABSTRACT
The characteristics of a successful financial forecasting system are the exploitation of inefficiencies of a given market and the precise application to that market. Overwhelming evidence indicates that opportunities exist for consistent positive returns over a given period of time. This project aims to provide means for the yield curve projection of government bonds. An ensemble of networks such as back propagation, radial basis function, linear regression, is used to predict the yield. The yield is forecasted using technical analysis using historical data and the output is tested for accuracy and accordingly assigned weights. Using the ensemble of neural networks, accuracy has been tried to be maximized and offer near to actual prediction. Using the yield curve, the investor can assess not only the yield of that bond, but can also the interest rates, and hence, has a very useful tool in his hand for investment purpose, thus making decisions about whether to invest or not , and if invest then when to invest. The yield curve prediction not only provides the investor a tool to make investment decisions in bond market, but it also serves as a tool to gauge the macroeconomic conditions of the country and hence predict the movement in various other markets as well, and hence make investment decisions accordingly.

General Terms
Your general terms must be any term which can be used for general classification of the submitted material such as Pattern Recognition, Security, Algorithms et. al.

Keywords
Ensemble, ANN, BPN, RBF, Bonds, Financial Forecasting.

1. INTRODUCTION
W Debt instruments are contracts in which one party lends money to another on pre-determined terms with regard to rate of interest to be paid by the borrower to the lender, the periodicity of such interest payment, and the repayment of the principal amount borrowed (either in installments or in bullet)[4]. In the Indian securities markets, we generally use the term "bond‟ for debt instruments issued by the Central and State governments and public sector organizations, and the term "debentures‟ for instruments issued by private corporate sector. The investors lend money to the government for a rate of interest to be paid by the government, and the principal is returned to the investor at a predetermined maturity date. The key terminologies in the bond are Principal, which is the amount that has been borrowed by the government; Coupon, which is the interest paid to the lender by the borrower either semi-annually or annually; Maturity, which is the date on which the principal is returned back to the lender; and Market price, which is the price at which the bond is being traded in the market[1]. The most important parameter to be considered by the investor is the Yield, which is the return that the investor gets on buying the bonds at the market price and retaining it till the maturity.

Government bonds are used for the following reasons

A. The risk involved in lending money to a national government is much less than that involved with private companies as they provide sovereign‟s commitment to repay the principal and the interest. Hence, from the investor point of view, it‟s a low-risk and good-return investment.

B. The volume of bonds issued in terms of money is three times that of the money involved in equity market of the country, and hence, is a large market.

C. The volatility involved in the yield is comparatively less, and hence can be predicted to a greater level for investment purpose.

D. The maturity period of a Government security varies in a wide range from 90 days to 30 years which is decided based on the bank's liabilities[6]. Also the investor can redeem the bonds before the maturity date at market value.

2. ENSEMBLE OF NEURAL NETWORKS
Ensemble of artificial neural networks is now being used widely by neural network practitioners due to its wide range of applications. Ensemble is a method in which we combine number of neural networks to enhance the output [7]. Most of the neural networks are designed to produce linearity or non linearity in the data but there arises model wherein we are supposed to track the linearity and non linearity in the data and produce desirable outputs. In such cases ensemble neural networks play a major role as it combines various neural networks to form a single model. In our model for prediction we have used one Back propagation network, one linear regression network and two Radial basis function. The purpose for using two radial basis function will be understood when we analyze the output tables. There are many different ensemble techniques but have used weighted average technique.

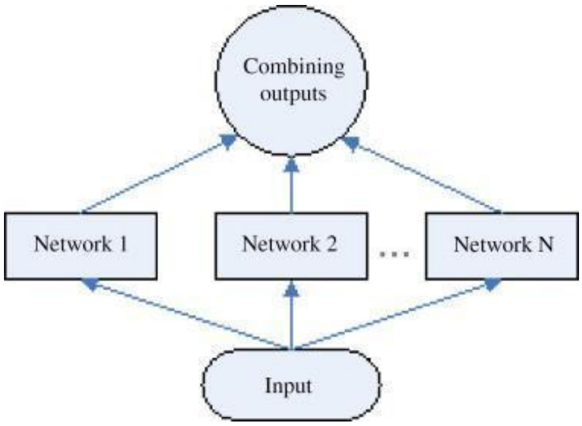

Fig 1: A classifier ensemble of neural networks.

We have used the following networks for our ensemble, the details of which are given below.

2.1 Back Propagation Network

Back Propagation is probably the most commonly used neural network amongst all other feed-forward networks. In this network the signal travels in the forward direction and the calculated error then travels in the backward direction which is used to adjust the weights in order to reduce the error [5].

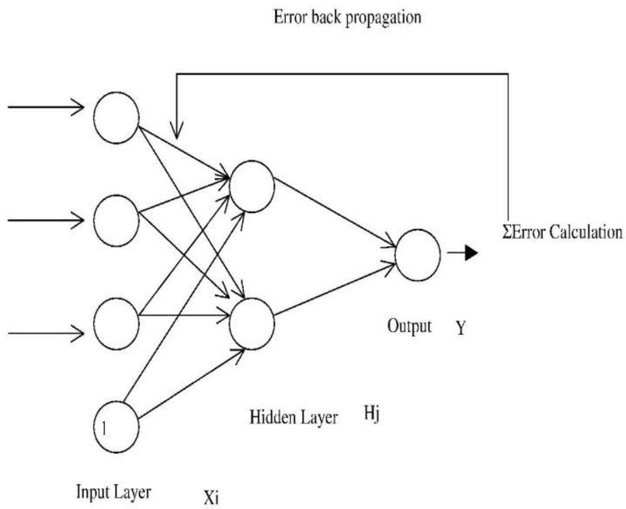

Fig 2: Architecture of Back Propagation Network.

2.2 Radial Basis Function

The RBF network is a single-hidden-layer feed forward neural network. Each node of the hidden layer has a parameter vector called centre. This centre is used to compare with the input signal to produce a Gaussian response. The network output is a result of the combination of the response of the hidden layer which is scaled by the connection weights[3]. The radial basis functions in the hidden layer produces a significant non-zero response only when the input falls within a small localized region of the input space. Each hidden unit has its own receptive field in input space. The most popular radial function is Gaussian activation function.

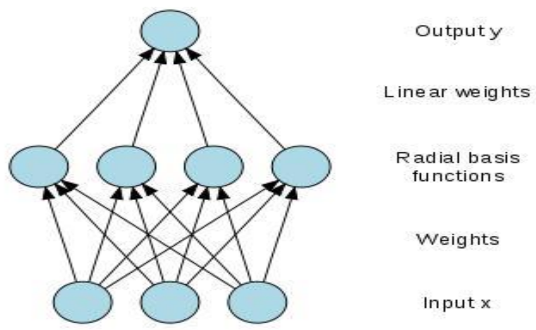

Fig 3: Architecture of Radial Basis Function.

2.3 Linear Regression Model

Linear regression is an approach to modeling the relationship between more than one explanatory variable denoted X and a dependent scalar variable y [2]. The case of one explanatory variable is called simple linear regression. A process is said to be an autoregressive process of order p if

$$y_t = \mu + \varphi(1)y(t-1) + \varphi(2)y(t-2) + \ldots + \varphi(p)y(t-p) + \varepsilon(t)$$

where ,

$\varphi(i)(i = 1, 2, \ldots, p)$ are the autoregressive parameters

μ is the mean of the series

$\varepsilon(t)$is a random process with a mean of zero and a constant variance of δ.

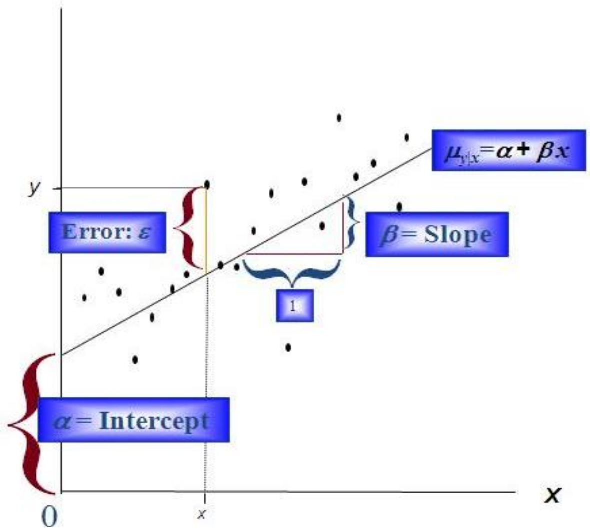

Fig 4: Linear Regression Plot

3. IMPLEMENTATION

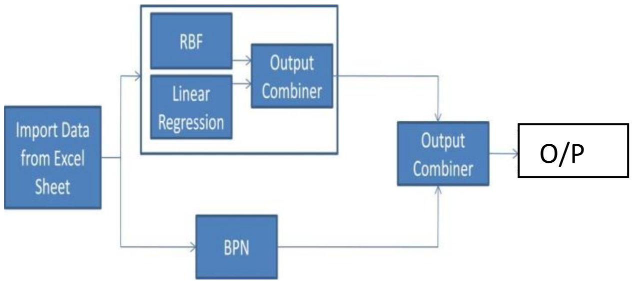

Fig 5: Technical Analysis Flowchart.

The project involves the use of MATLAB software. The explanation of the above flowchart is as follows:

A. Historical data for the bond is obtained and checked for veracity. This is required to ascertain that the data is correct and matches with the date.

B. The data is compiled into proper format in Microsoft Excel, from where it is imported into MATLAB.

C. The data is divided into two sets, one is used for training and the other is used for testing of the trained neural network. For training, 40 sets each containing 50 values are made, and corresponding target values are noted for each set. These sets are used for training the neural networks. For testing, 6 sets are made, each containing 50 values and the corresponding target values are noted, which is used to check the accuracy of the network.

D. Using the MATLAB software, neural networks with required parameters is constructed and trained using the above mentioned compiled data sets.

E. To check the accuracy of each network, the testing sets are used, and the accuracy with variable parameters is determined.

Finally, for the 5day and 10day prediction, the network with the parameter with highest accuracy is selected separately, and the outputs of the three selected networks are combined using weighted average technique, whereby the network with maximum accuracy is assigned maximum weight

4. METHODOLOGY

The 11.50% bond data from the year 1998 to 2012 was available. The data is used for training and testing. First 2000 data points are used for training purpose. The next 300 data points are used for simulation. The neural network finds the relation between the successive inputs and develops an approximate function of it. It simply extrapolates the curve when provided with the last set of input values. The various networks used and the nntool manager in MATLAB is shown as below.

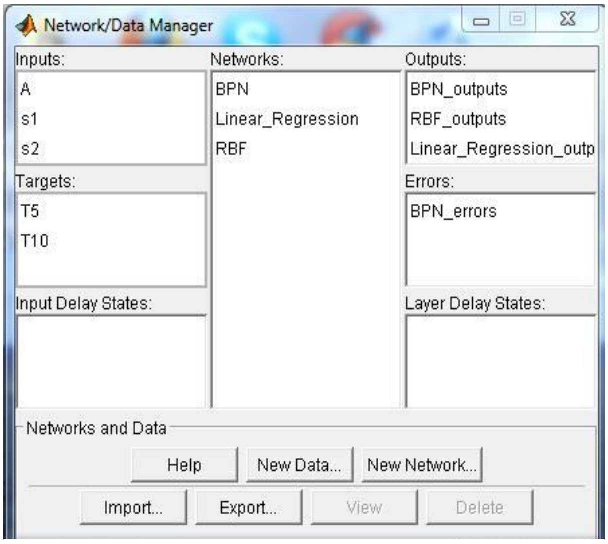

Fig 6: Implementing Neural Networks In nntools.

In the above window, it can be seen that A, S1 and S2 are the inputs to the neural networks. It consists of historical values of the bond prices which are divided into 10 data groups each consisting of 50 data points. T5 and T10 are the 5 day and 10 day prediction targets respectively. The 3 networks used are back propagation, radial basis and linear regression.

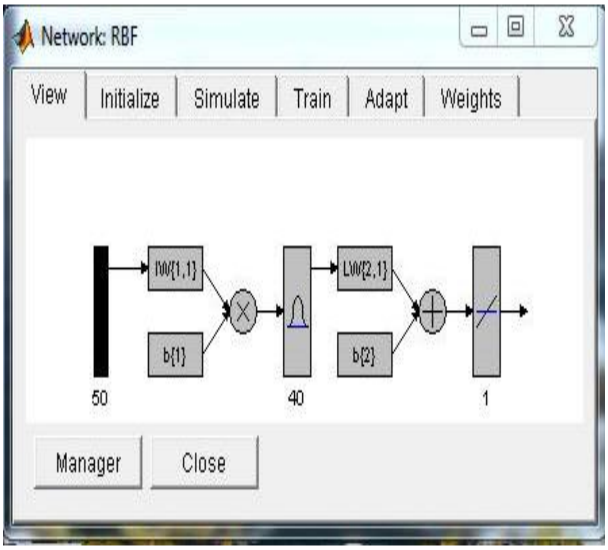

Fig 7: Radial Basis Function Network.

In the above neural network there are 50 input neurons, 40 hidden neurons and 1 output neuron. b(1) signifies the bias weights for the hidden layer. lW(1,1) signifies the weights from the input neurons to the hidden neurons. b(2) signifies the bias weights for the output layer. LW(2,1) signifies the weights from the hidden neurons to the output neuron. The hidden layer uses Gaussian kernel activation function and the output layer uses a linear activation function.

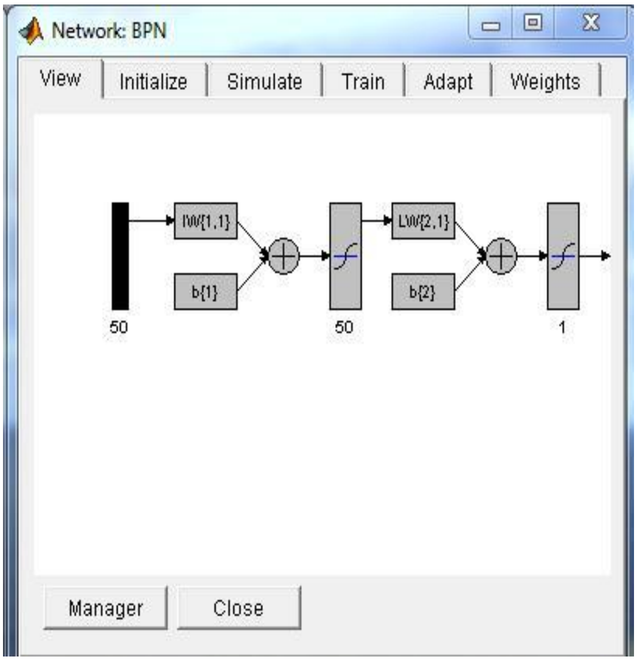

Fig 8: Back Propagation Network

In the above neural network there are 50 input neurons, 50 hidden neurons and 1 output neuron. b(1) signifies the bias weights for the hidden layer. IW(1,1) signifies the weights from the input neurons to the hidden neurons. b(2) signifies the bias weights for the output layer. LW(2,1) signifies the weights from the hidden neurons to the output neuron. The hidden and output layer use bipolar sigmoidal activation function.

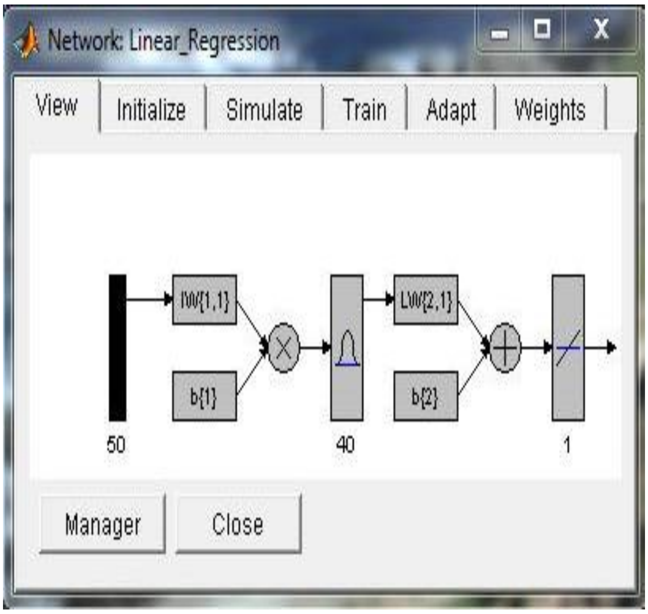

Fig 9: Linear Regression Network

The architecture used here is identical to that use in radial basis network.

5. RESULTS

The following tables indicate the various networks created, with the corresponding parameters, and the output results for each of them. The results indicate the actual values versus the values obtained from each of the networks, and the percentage error for each network.

5.1 Back Propagation Network

For BPN, the parameters that are varied are number of hidden layers and the number of hidden neurons which caused changes in number of epochs.

Table 1. 5-day Prediction Model

Name	**Bpn1_5**	**Bpn2_5**	**Bpn3_5**
Epoch	11	6	26
Hidden layers	1	1	2
Hidden neurons	50	50	40
Actual values	Predicted Values		
7.709	8.217	7.947	7.761
7.572	7.312	7.448	7.462
7.700	8.056	7.354	7.771
7.682	7.917	7.833	7.815
7.544	7.280	7.312	7.437
7.857	8.111	7.876	7.953
Error %	1.736	1.127	0.524

Table 2. 10-day Prediction Model

Name	**Bpn1_10**	**Bpn2_10**	**Bpn3_10**	**Bpn4_10**	**Bpn5_10**
Epoch	12	13	9	15	9
Hidden layers	1	1	2	1	1
Hidden Neurons	50	50	70	70	50
Actual values	Predicted values				
7.7259	8.240	8.357	7.8404	8.2192	7.898
7.4268	7.493	7.875	7.6929	7.9468	7.472
7.4189	7.864	8.054	7.8755	8.1277	7.682
7.6828	7.962	8.117	7.8568	8.1254	7.849
7.8571	7.439	7.647	7.5801	7.7691	7.361
7.8605	7.716	8.142	7.8707	8.1075	8.010
Error %	1.870	2.520	1.3991	2.5019	1.355

5.2 Radial Basis Function Network

Since RBF has only one hidden layer, the parameter that is varied is the spread of the Activation function of the hidden layer which effectively varies the number of centers.

Table 3. 5-day Prediction Model

Name	**Rbf1_5**	**Rbf2_5**	**Rbf3_5**	**Rbf4_5**	**Rbf5_5**
Spread	1.57	1	2	0.8	0.85
Actual values	Predicted values				
7.709	5.686	7.267	6.410	8.054	8.078
7.572	5.666	7.268	6.419	8.054	8.077
7.700	7.239	7.390	7.569	8.099	8.000
7.682	7.14	7.390	7.503	7.968	7.964
7.544	7.034	7.374	7.244	7.918	7.903
7.857	6.520	7.368	7.184	8.054	8.077
Error %	6.958	1.852	4.128	1.833	1.872

Table 4. 10-day Prediction Model

Name	**Rbf1_10**	**Rbf2_10**	**Rbf3_10**	**Rbf4_10**
Spread	1	0.8	0.85	0.75
Actual values	Predicted Values			
7.725	7.242	8.013	8.035	7.995
7.426	7.242	8.013	8.034	7.995
7.418	7.354	7.966	7.963	7.967
7.682	7.327	7.914	7.905	7.922
7.857	7.313	7.860	7.840	7.879
7.860	7.340	8.013	8.034	7.995
Error %	2.102	1.997	2.043	1.959

5.3 Linear Regression model

For linear regression model, the parameter that is varied is the spread

Table 5. 5-day Prediction Model

Name	**Lr1_5**	**Lr2_5**	**Lr3_5**
Spread	1	11	0.9
Actual values	Predicted Values		
7.709	7.496	7.494	7.502
7.572	7.506	7.497	7.519
7.700	7.603	7.591	7.619
7.682	7.556	7.558	7.553
7.544	7.504	7.505	7.504
7.857	7.887	7.841	7.931
Error %	0.604	0.618	0.597

Table 6. 10-day Prediction Model

Name	**Lr1_10**	**Lr2_10**	**Lr3_10**	**Lr4_10**
Spread	1	0.9	0.8	0.85
Actual values	Predicted Values			
7.725	7.390	7.391	7.395	7.393
7.426	7.391	7.398	7.404	7.401
7.418	7.548	7.564	7.585	7.574
7.682	7.457	7.447	7.435	7.441
7.857	7.411	7.405	7.400	7.402
7.860	7.842	7.888	7.924	7.908
Error %	1.321	1.347	1.376	1.361

5.4 Ensemble Outputs

The various neural networks outputs are put in tabular format as above and compared in order to get the accurate values. An ensemble of network was able to reduce the error to a great extent.

5.4.1 5 day Prediction

The radial basis function networks rbf5_5 and rbf2_5, when combined, gave a better output predicted values. These two networks were given equal weights.

rbf(comb) = (rbf5_5 + rbf2_5)/2

The back propagation network bpn2_5 was used along with linear regression lr3_5.

The 3 networks: back propagation network, linear regression model and combination of radial basis function model were combined and suitable weights were assigned. It was found that radial basis function ensemble gave the nearest value to actual values, followed by back propagation network and then by linear regression.

The final output was as:

o/p_5 = 0.25*bpn2_5 + 0.15*lr3_5 + 0.6*rbf(comb)

Table 7. 5-day Prediction Model

Name	Bpn2_5	Error %	Lr3_5	Error %	Rbf(comb)	Error %	o/p_5	Error %
Actual values	Predicted values							
7.709	7.947	0.030	7.502	-0.0269	7.672	-0.004	7.716	0.084
7.572	7.448	-0.016	7.519	-0.006	7.673	0.013	7.593	0.275
7.700	7.354	-0.044	7.619	-0.010	7.699	-0.001	7.696	-0.058
7.682	7.833	0.019	7.553	-0.016	7.675	-0.001	7.695	0.166
7.544	7.312	-0.030	7.502	-0.005	7.638	0.012	7.536	-0.094
7.857	7.876	0.002	7.931	0.009	7.723	-0.017	7.792	-0.822
Error	1.127		0.597		0.423		0.149	

5.4.2 10 day Prediction

The radial basis function networks rbf1_10 and rbf2_10, when combined, gave a better output predicted values. These two networks were given equal weights.

rbf(comb) = (rbf1_10 + rbf2_10)/2

The back propagation network bpn5_10 was used along with linear regression lr1_10.

The 3 networks; back propagation network, linear regression network and combination of radial basis function model were combined and suitable weights were assigned. It was found that radial basis function ensemble gave the nearest value to actual values, followed by back propagation network and then by linear regression.

The final output was as:

o/p_10 = 0.3*bpn5_10 + 0.1*lr1_10 + 0.6*rbf(comb)

Table 8. 5-day Prediction Model

Name	Bpn5_10	Error %	Lr1_10	Error %	Rbf(comb)	Error %	o/p_10	Error %
Actual values	Predicted values							
7.725	7.898	0.022	7.390	-0.043	7.627	-0.012	7.685	-0.525
7.426	7.472	0.006	7.391	-0.004	7.627	0.027	7.557	1.761
7.418	7.682	0.035	7.548	0.017	7.660	0.032	7.656	3.195
7.682	7.849	0.021	7.457	-0.029	7.621	-0.008	7.673	-0.125
7.857	7.361	-0.063	7.411	-0.056	7.586	-0.034	7.501	-4.525
7.860	8.010	0.019	7.842	-0.002	7.677	-0.023	7.793	-0.852
Error	1.355		1.321		1.020		0.983	

6. PLOTS

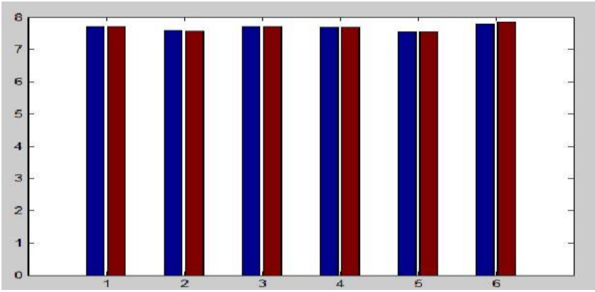

Fig 10: 5 Day Prediction

We can deduce from the plot that the initial prediction are more accurate because the test data is immediately after the training set. As we move towards right side of plot the accuracy decreases, as the data is less co-related to the training set.

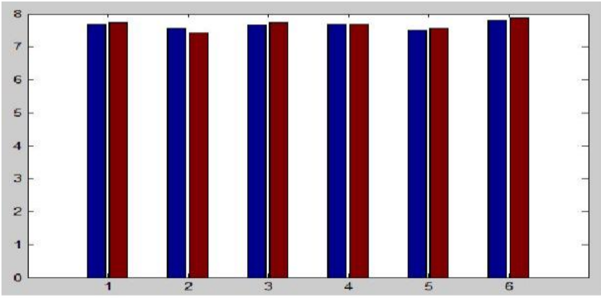

Fig 11: 10 Day Prediction

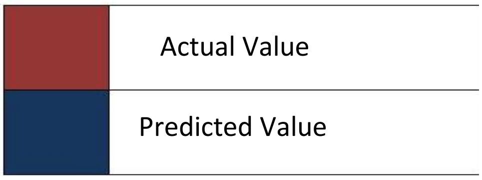

Fig 12: Key to figure 10 and figure 11.

We can infer from 10 day prediction plot that as compared to 5 day prediction model, it is less accurate. This is because the day gap between last trained input data point and output is increased and hence the lower accuracy. Also the error creeps in as we widen the gap and predict a more futuristic value.

7. CONCLUSIONS

The model used for prediction was tested efficiently for variety of data proving the efficiency of the model. Various parameters for neural networks were being varied and experimented while selecting the appropriate neural network. The data of 20-year 11.50% coupon bond maturing in 2015 was used. The 5 day prediction ensemble model gave an error of 0.149%, whereas the 10 day one gave and error of 0.9833%. From the results it can be inferred that the model has been designed within the permissible range of error for practical use. The efficiency of the model can be improved by increasing the data sets used for learning. The model can even be remodelled to be used for prediction using fundamental analysis by gaining suitable knowledge in the field of economics.

8. ACKNOWLEDGMENTS
We, hereby take this opportunity to thank all those who have helped us in making this project a success. It wouldn't have been possible without the constant guidance of our teachers and the support of our families.

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