Modeling and Forecasting for the Growth of Carbon dioxide emission in India

A report submitted in the fulfilment of the requirement for the Award of the degree of

Master of Technology
Industrial and Systems Engineering

Submitted By

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CERTIFICATE

This is to certify that the project titled “**Modeling and Forecasting for the Growth of Carbon dioxide emission in India**” is a bonafide work carried out by ***Piyush Anand***, Roll no. 17QE30002, under my supervision and guidance. This report, in my opinion, is worthy of consideration for partial fulfilment of requirements for the degree of Master of Technology in Industrial and Systems Engineering in accordance to the regulations of this institute.

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DECLARATION

I attest to the fact that –

The work in the thesis is entirely original and was completed under the overall supervision of my supervisor. There has been no presentation of a work to any other institute for a degree or diploma. In thesis writing, I followed instructions provided by the Institute.I followed the Institute's Moral Rule of Conduct's norms and guidelines.I have provided deserved importance to other sources whenever I have used materials (data, theoretical analysis, and text) from them by citing them in the thesis text and giving their contact details in the references.

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1. Introduction

Harmful activities of human beings have increased the level of carbon dioxide in the atmosphere, thereby accelerating Earth's greenhouse effect. Despite global pandemic, average amount of carbon dioxide globally hit a new record high. The annual rate of increase in atmospheric carbon dioxide over the past 60 years is 100 times faster than previous natural increase. The oceans have absorbed enough carbon dioxide to increase their acidity by 30%.

Although India's percentage carbon dioxide emissions rose slower in years 2016-19 than in years 2011-15 but was much above the world average of 0.7%.

In 2020, when the Covid-19 pandemic shook economic growth of many countries, India's emissions fell 9.7%, a little more than the world average of 9.6%.
In 2020, lockdowns to tackle the COVID-19 pandemic cut global emissions of carbon dioxide by 2.6 billion tonnes.

However, few analysts believe 2020 was a special case when the emission of carbon dioxide actually came down that realistically it cannot continue for long as the world overwhelmingly relied on fossil fuels, and lockdowns as such are neither a sustainable nor desirable solution to the climate crisis.

Some of the chief sources of carbon dioxide emission are power generating plants, iron and steel industry, petrochemical industry, cement production, and transport.

In the first part of the project we compared two different forecasting techniques namely ARIMA and SeriesNet. ARIMA is a forecasting technique that explains a given time series based on its own past values, i.e, its own lagged values and the forecast errors of previously predicted values, so that equation can be used to forecast future values.

The SeriesNet on the other hand consists of two networks. The LSTM network aims to learn connected features and reduces the dimensionality of multi-conditional data, and the dilated causal convolution network learns information from different time intervals. SeriesNet can learn multi-range and multi-level features from time series data, and has higher predictive accuracy compared to those models using fixed time intervals. Moreover, this model adopts residual learning and batch normalization to improve generalization.

They were compared using MAPE, SMAPE, AMAPE, MAE, RMSE measurement techniques. Both the algorithms were trained on similar training data and values were forecasted for different horizons. Values predicted by both the algorithms were compared and hence both the algorithms were evaluated.
It was found that ARIMA performed better than SeriesNet for both small as well as big horizon.

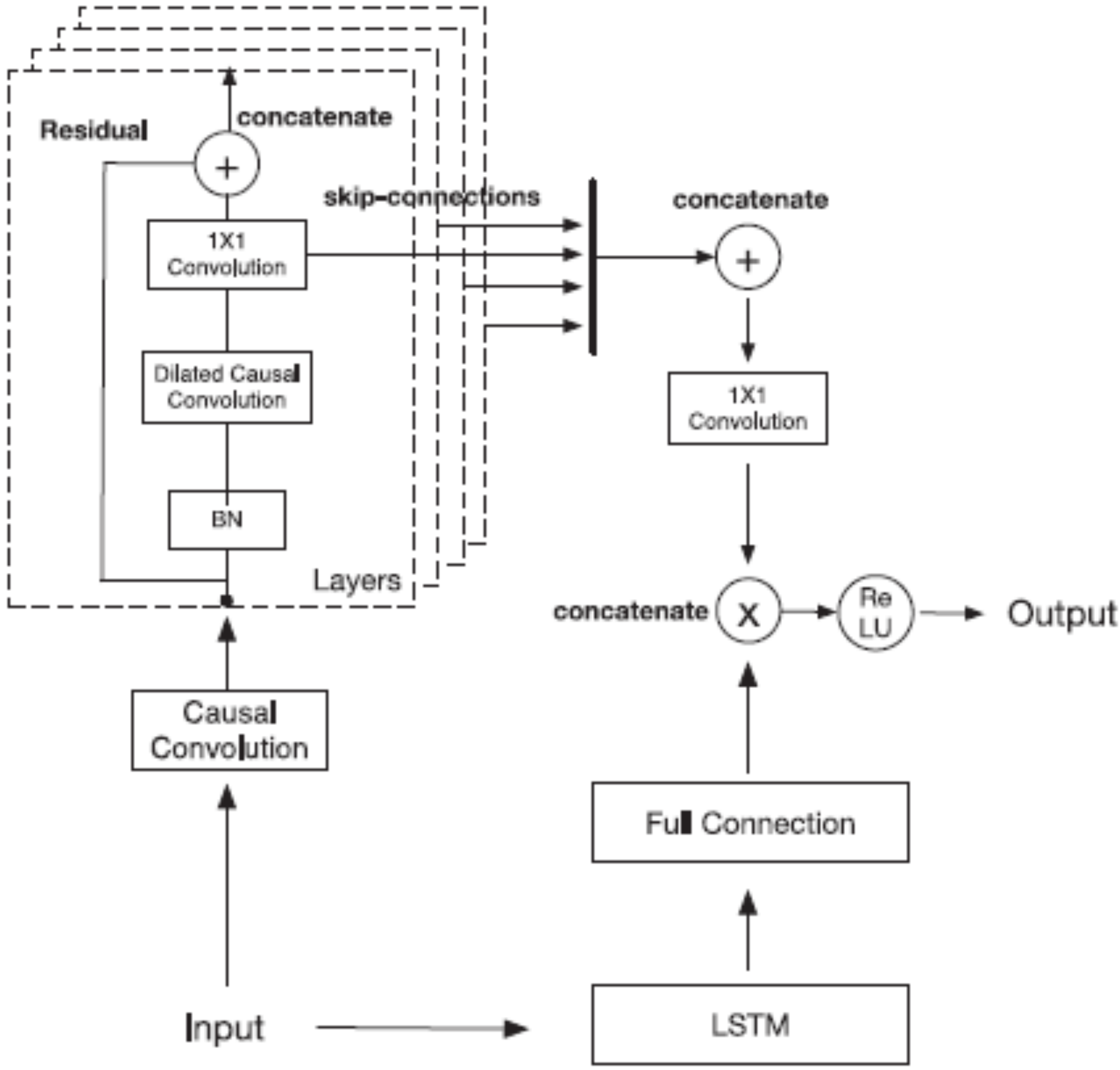

Fig 1: SeriesNet

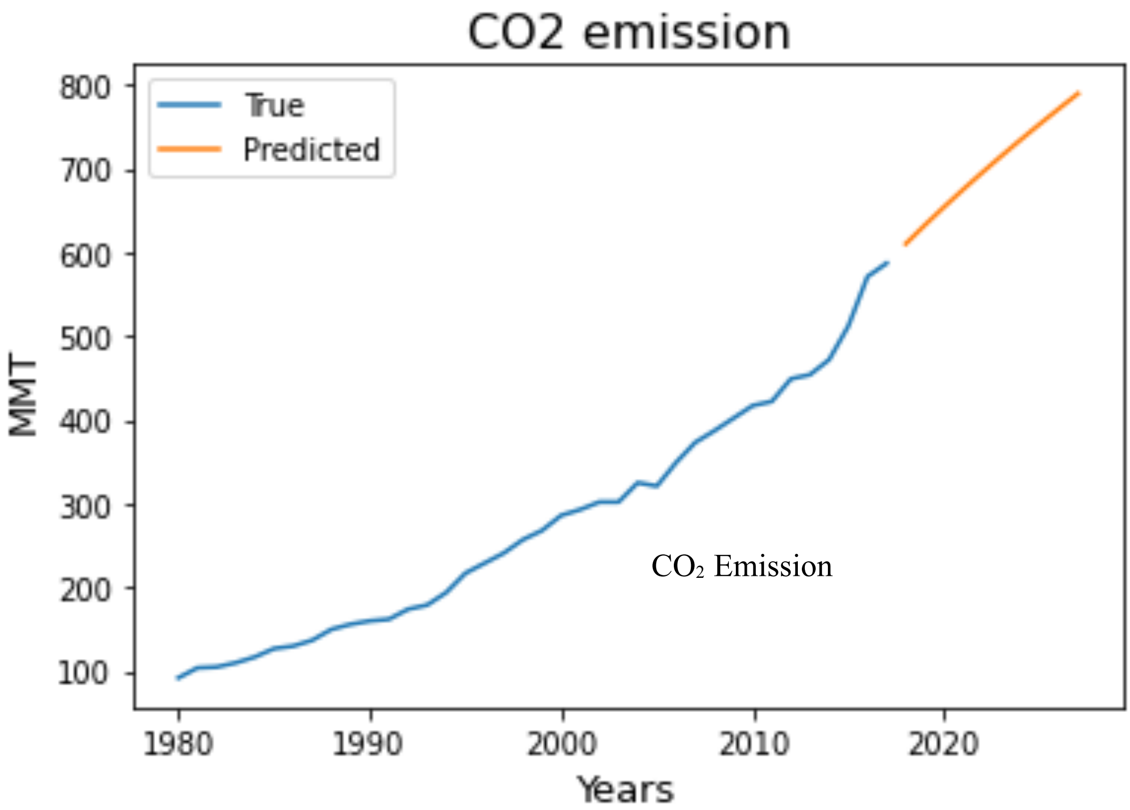

Fig 2: Result - Arima

2. Research Objectives

Study the growth of CO_2 emission of India and forecast India's future CO_2 emissions. Suggest ways to reduce CO_2 emission in India.

3. Methodology Framework

In this project we compare System Dynamics Model with modern day state of the art machine learning forecasting algorithm namely Prophet.
System Dynamics Methodology is modeling technique to frame, understand, and discuss complex issues and problems. It focuses on behaviour of the system, inter-relation between variables and identifies and uses measurable behaviours to build, study, simulate, observe and learn. Two central concepts of system dynamics theory are Causal loop diagrams (CLDs) and Stock and Flows.

Causal Loop Diagram (CLD): It is visual representation of the cause-effect relationships between the various elements of the system, forming feedback loop. It conceptualizes the problem and captures hypothesis about causes of dynamics.
Stocks and Flows: Stocks and flows, along with feedback are the two central concepts of system dynamics theory.
Stocks: It characterizes the state of system. It accumulates over time and provides data to help make decisions.
Flows: It causes stocks to change over time.
Auxiliary variable or Information: It helps define other instantaneous variables/ calculations.
Prophet on the other hand is an open source library published by Facebook that is based on decomposable (trend+seasonality+holidays) models. It provides us with the ability to make time series predictions with good accuracy using simple intuitive parameters and has support for including impact of custom seasonality and holidays.

4. Literature Review

In China, Sun found out that by 2010 CO2 emission in China would be approximately 1990 mega metric ton(s) by analyzed emission patterns for all 30 provinces using ARIMA models.

Lotfalipour predicted that the amount of carbon dioxide emissions will reach up to 925.68 million tons in 2020 in Iran by using ARIMA models over the period 1965 to 2010.

Basak & Nandi, analyzed the dynamics of CO_2 emissions in India using a dataset ranging over the period 1980 – 2000 by employing a Differential Model and revealed that CO2 emissions will increase in India over the period 2015 – 2020.

Rahman & Hasan, used time series data from 1972 to 2015, based on and revealed that the ARIMA (0, 2, 1) model is the most suitable model for modeling and forecasting carbon dioxide emission in Bangladesh.

5. Materials and Methods

As mentioned above in this second part of project system dynamics model was compared with Prophet.They were compared using MAPE, SMAPE, AMAPE, MAE, RMSE measurement techniques.

Finally, best performing models from first and second part of the project were compared using MAPE, SMAPE, AMAPE, MAE, RMSE measurement techniques.

Ultimately, from the best performing algorithm future values of carbon dioxide emission of India were predicted.

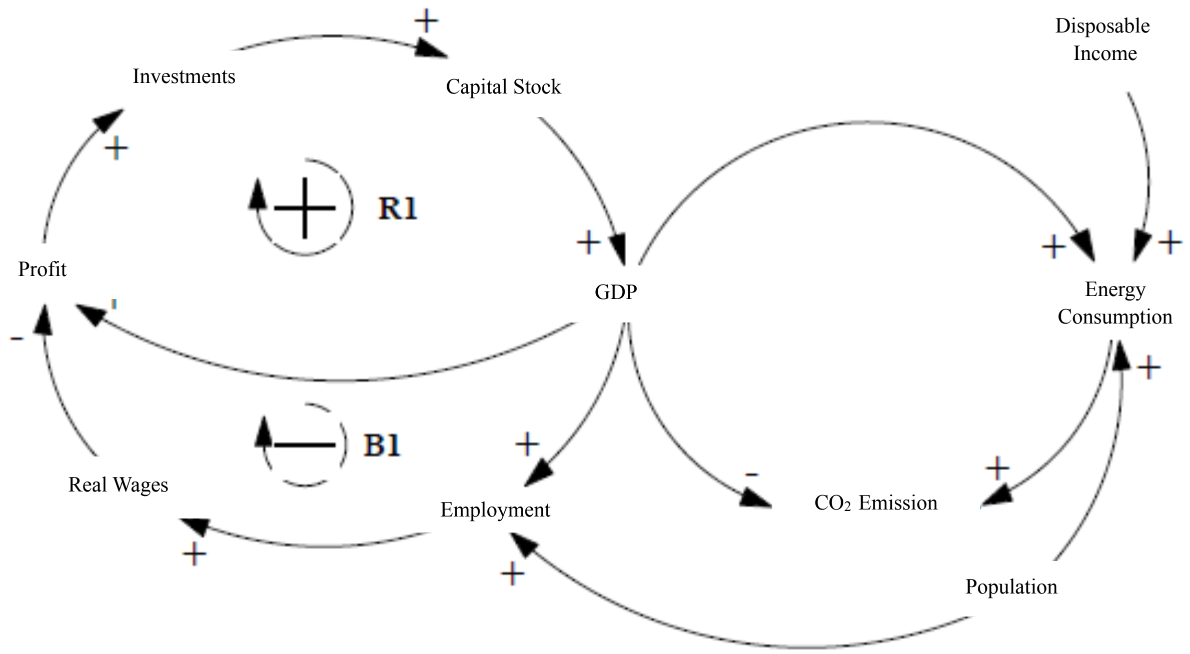

Fig 3: Causal Loop Diagram (CLD)

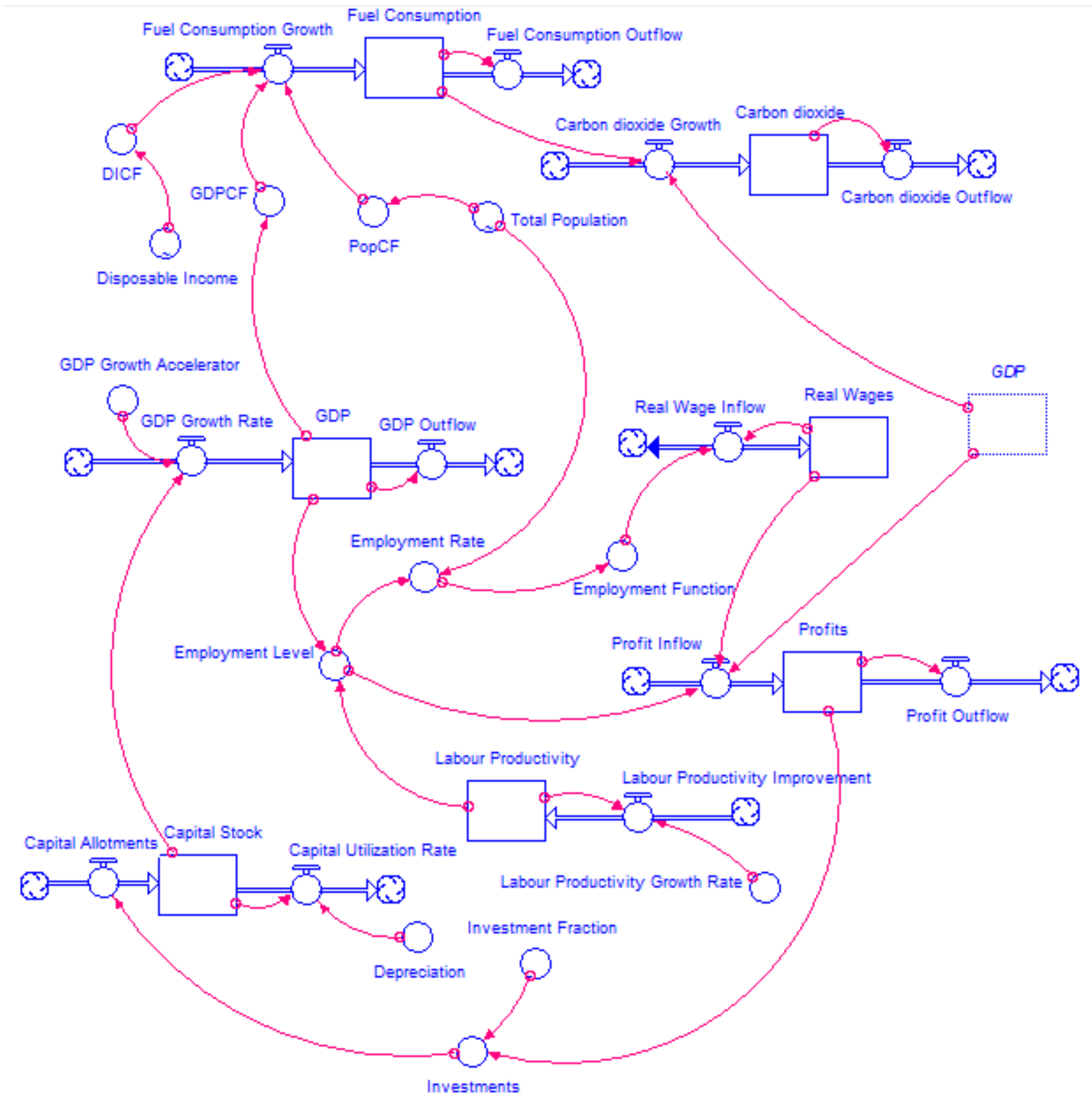

Fig 4: Stock and Flow Diagram

6. The Data Collection

The data was collected from United Nation's website. The original dataset contained information about GDP, Crude Oil consumption, capital, labour, Carbon dioxide emission etc of India from 1980 to 2017.

Link to the dataset: https://tinyurl.com/2uyy5suw

7. Results and Discussion

In the second part of project System Dynamics model was compared with Prophet for carbon dioxide emission from 1980 to 2017 with actual values using various forecasting error analyzing methods namely MAPE, sMAPE, aMAPE, MAE, RMSE. Prophet was found to be performing better than System Dynamics on the training dataset.

	MAPE	sMAPE	aMAPE	MAE	RMSE
System Dynamics	37.52	48.068	30.139	83.542	93.726
Prophet	2.590	2.592	2.684	7.441	10.314

Table1: Comparison between System Dynamics and prophet

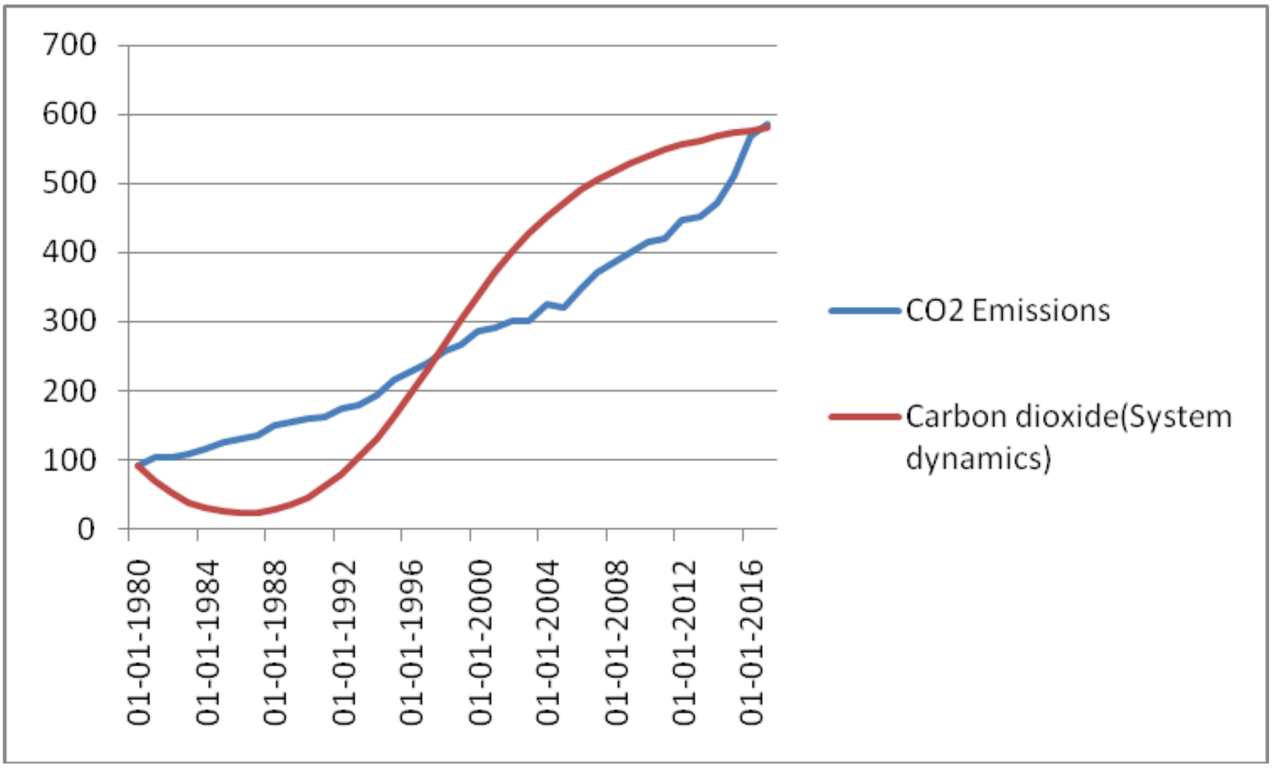

Fig 5: Result - System Dynamics Model

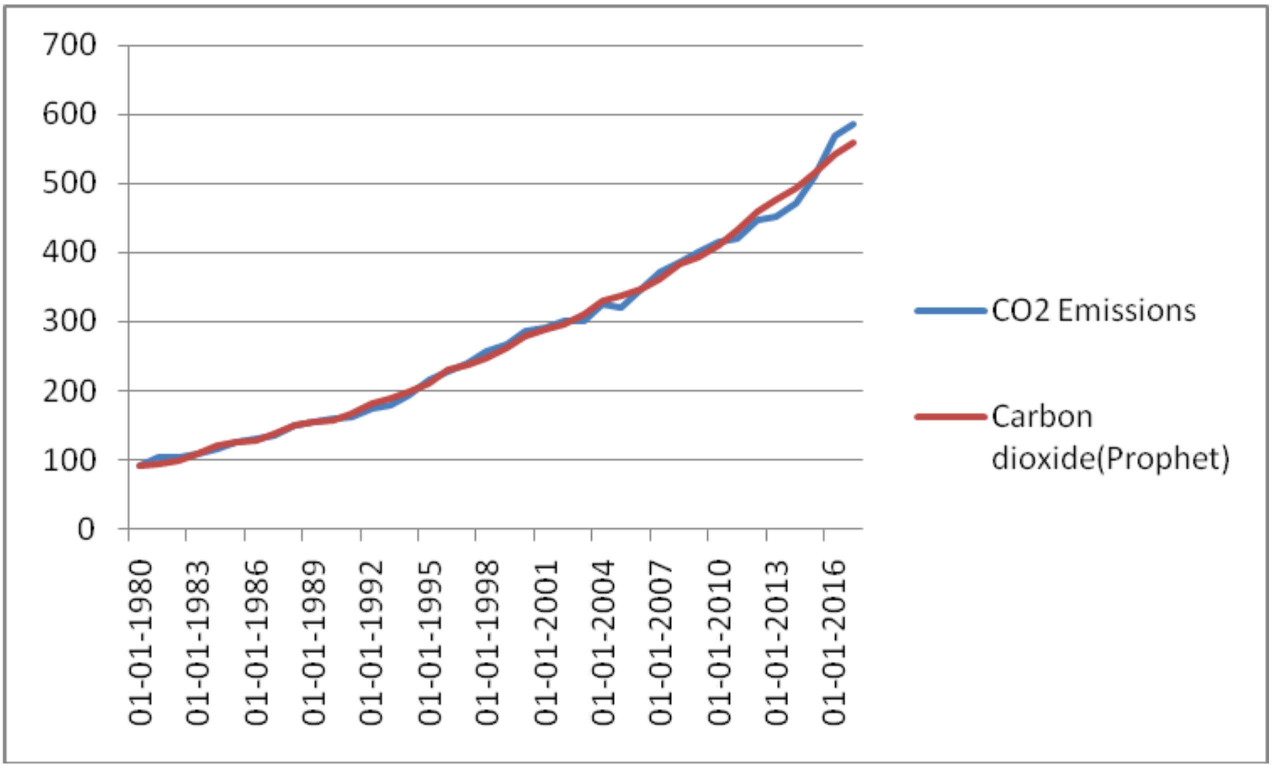

Fig 6: Result - Prophet

Finally, Prophet was compared with ARIMA for different horizon(s) using MAPE, sMAPE, aMAPE, MAE, RMSE. It was found that Prophet performed better than ARIMA for big horizon.

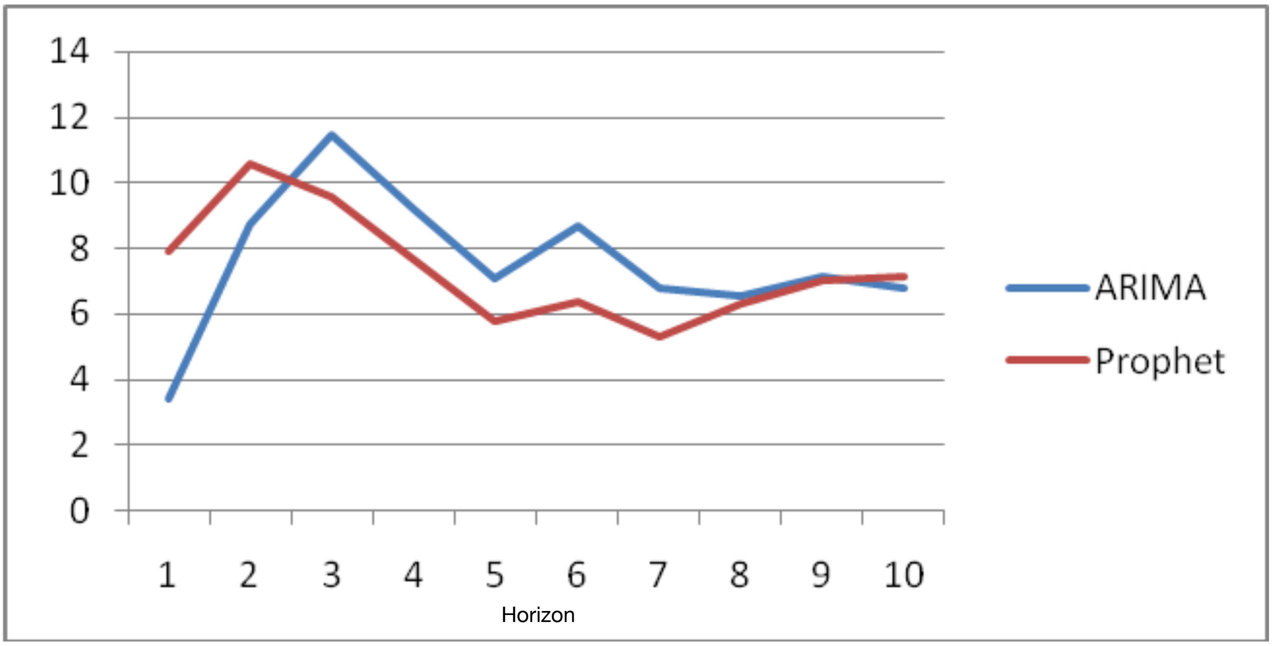

Fig 7: MAPE

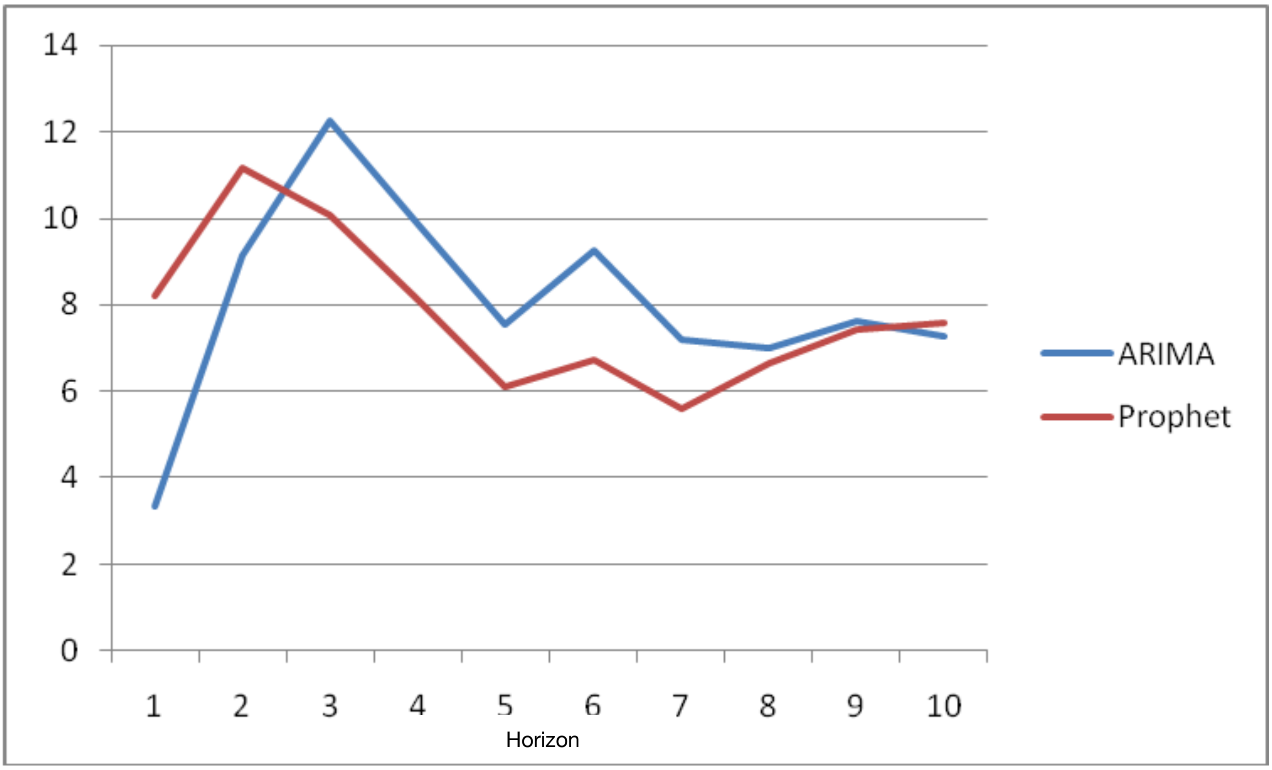

Fig 8: sMAPE

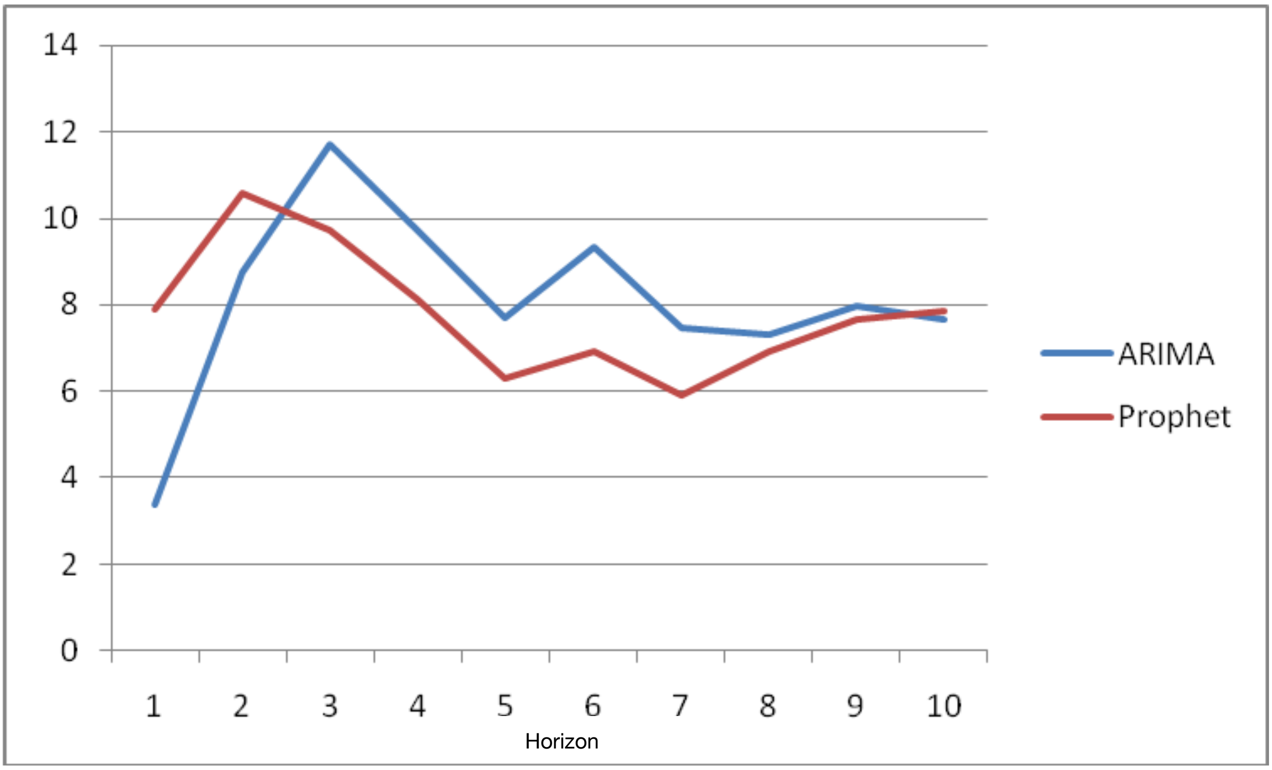

Fig 9: aMAPE

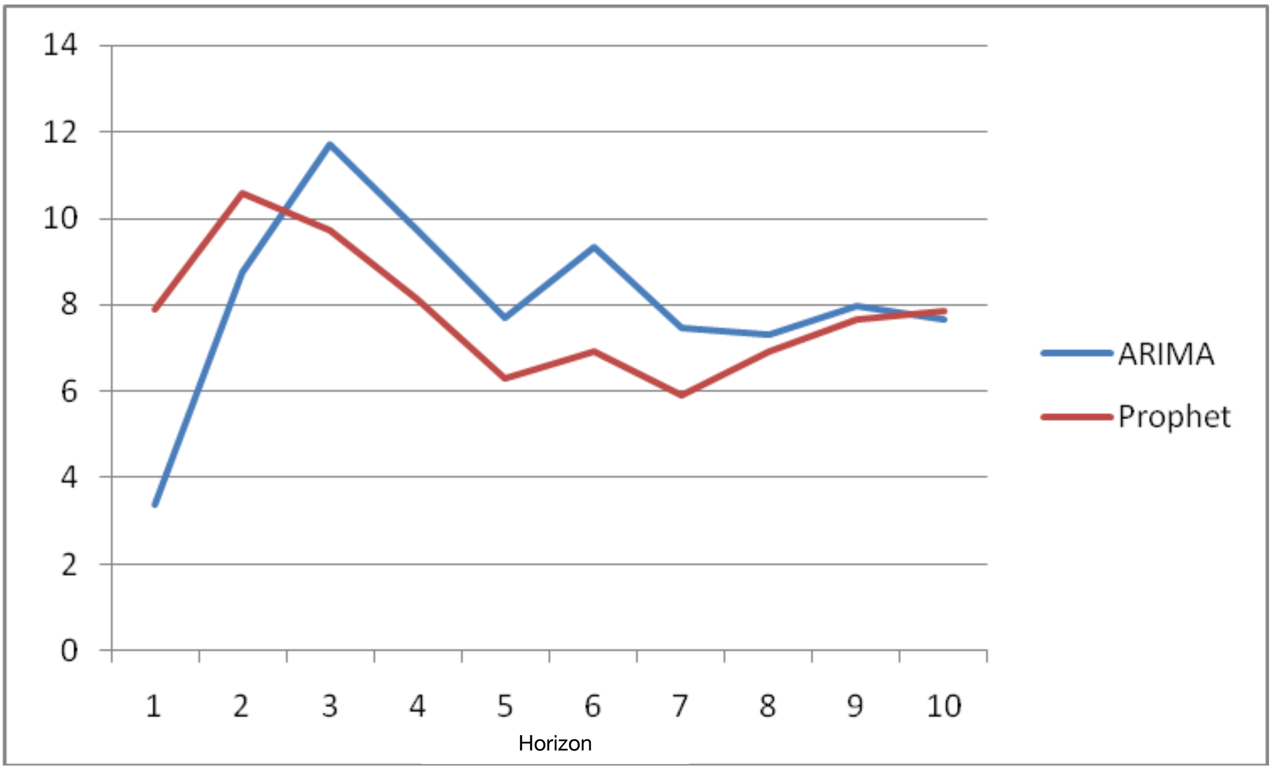

Fig 10: MAE

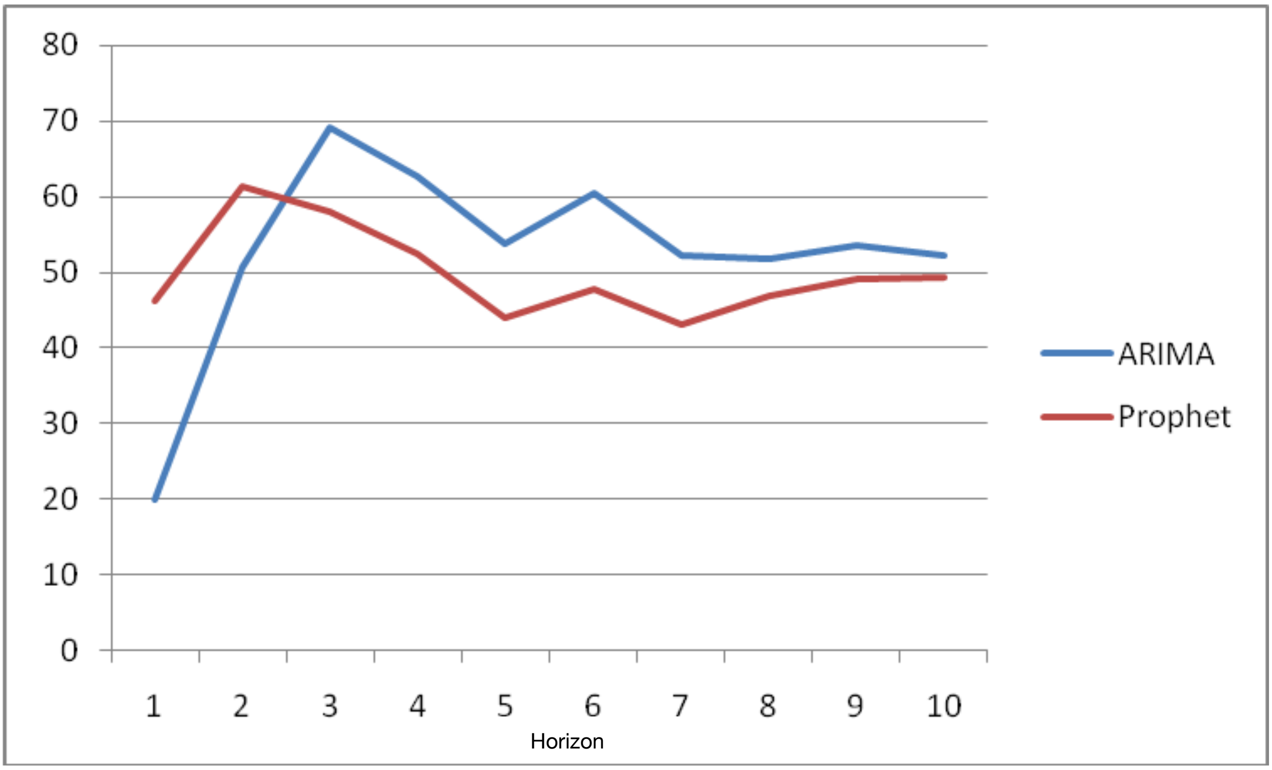

Fig 11: RMSE

Therefore, we chose Prophet over ARIMA to predict future values of Carbon dioxide emission of India.

8. Conclusions

After choosing PROPHET as the forecasting technique we predicted the future values of carbon dioxide emission of India for the next ten years. We observed that India's CO_2 emission will only go up which is a worrisome news. Our predicted values for the next 10 years in MMT are 576.389446, 598.297606, 625.326542, 641.887088, 658.673946, 680.582105, 707.611041, 724.171587, 740.958445,
762.866605. A graph showing actual values and predicted values is shown below.

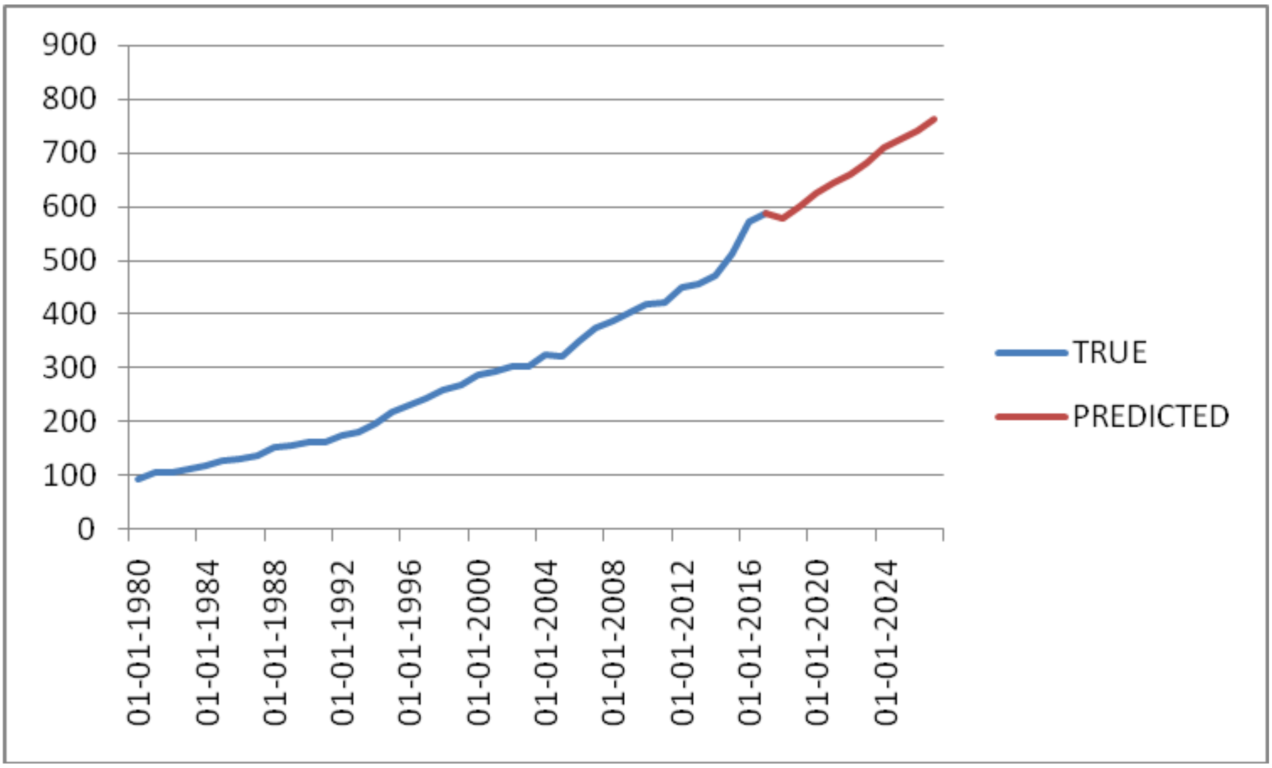

Fig 12: Forecast - CO_2

Hence, we urge strong action to be taken by the government to curb carbon dioxide emission.

Some of the steps government can take are as follows:-

- It can switch to clean energy by reducing consumption of coal and investing heavily in solar energy to generate electricity.
- It can run advertisements urging people to make their houses energy efficient and cutting upon unnecessary travels.
- It can educate people about deforestation and its ecological damages and urge people to plant and look after trees.

System dynamics forecasting model equations are given below.

1. State variable equations

Carbon dioxide(t) = Carbon dioxide(t - dt) + {(Carbon dioxide Growth – Carbon dioxide Outflow) x dt}

Fuel Consumption(t) = Fuel Consumption(t - dt) + {(Fue Consumption Growth – Fuel Consumption Outflow) x dt}

GDP(t) = GDP(t - dt) + {(GDP Growth Rate – GDP Outflow) x dt}

Labour Productivity(t) = Labour Productivity(t - dt) + {(Labour Productivity Improvement) x dt}

Real Wages(t) = Real Wages(t - dt) + {(Real Wage Inflow) x dt}

Profits(t) = Profits(t - dt) + {(Profit Inflow – Profit Outflow) x dt}

Capital Stock(t) = Capital Stock(t - dt) + {(Capital Allotments – Capital Utilization rate) x dt}

2. Rate equations

Carbon dioxide Growth = (GDP)/(Fuel Consumption x 1.5)

Carbon dioxide Outflow = Carbon dioxide

Fuel Consumption Growth = 16.2+(0.764 x GDPCF)-(0.607 x PopCF)+(0.172 x DICF)

Fuel Consumption Outflow = Fuel Consumption

GDP Growth Rate = Capital Stock/GDP Growth Accelerator

GDP Outflow = GDP

Labour Productivity Improvement = Labour Productivity x Labour Productivity Growth Rate

Real Wage Inflow = Employment Function x Wages

Profit Inflow = GDP - (Real Wages x Employment Level)

Profit Outflow = Profits

Capital Allotments = Investments

Capital Utilization Rate = Capital Stock x Depreciation

3. Auxiliary variable equations

GDPCF = loge(GDP)

PopCF = loge(Total Population)

DICF = loge(Disposable income)

Phillips Curve for Employment Function = -c+(d x Employment Rate)

Employment Level = GDP/Labour Productivity

Employment Rate = Employment Level/Total Population

Investments = Profits x Investment Fraction

4. Table functions

Disposable income = Graph(Time)
(1.00, 8.51), (2.00, 8.65), (3.00, 8.76), (4.00, 8.90), (5.00, 9.02), (6.00, 9.16), (7.00, 9.28), (8.00, 9.43), (9.00, 9.51), (10.0, 9.65), (11.0, 9.72), (12.0, 9.80), (13.0, 9.87), (14.0, 9.91), (15.0, 10.00), (16.0, 10.1), (17.0, 10.2), (18.0, 10.3), (19.0, 10.4), (20.0, 10.6), (21.0, 10.7), (22.0, 10.8), (23.0, 11.0), (24.0, 11.1), (25.0, 11.5), (26.0, 11.6), (27.0, 11.7)

Total Population = Graph(Time)
(1.00, 8.7e+008), (2.00, 8.9e+008), (3.00, 9.1e+008), (4.00, 9.3e+008), (5.00, 9.5e+008), (6.00, 9.6e+008), (7.00, 9.8e+008), (8.00, 1e+009), (9.00, 1e+009), (10.0, 1e+009), (11.0, 1.1e+009), (12.0, 1.1e+009), (13.0, 1.1e+009), (14.0, 1.1e+009), (15.0, 1.1e+009), (16.0, 1.1e+009), (17.0, 1.2e+009), (18.0, 1.2e+009), (19.0, 1.2e+009), (20.0, 1.2e+009), (21.0, 1.2e+009), (22.0, 1.3e+009), (23.0, 1.3e+009), (24.0, 1.3e+009), (25.0, 1.3e+009), (26.0, 1.3e+009), (27.0, 1.3e+009)

5. Parameters assumed to train the SD model

Depreciation = 0.039

GDP Growth Accelerator = 7.1

Investment Fraction = 0.41

Labour Productivity Growth Rate = 0.1

c = 3.25

d = 5

References

[1] A novel time series forecasting model with deep learning Zhipeng Shen, Yuanming Zhang , Jiawei Lu, Jun Xu, Gang Xiao, College of Computer Science & Technology, Zhejiang University of Technology, Hangzhou 310023, China.

[2] C. Cheng , A. Sa-Ngasoongsong , O. Beyca , T. Le , H. Yang , Z. Kong , S.T. Bukkap- atnam , Time series forecasting for nonlinear and non-stationary processes: a review and comparative study, IIE Trans. 47 (10) (2015) 1053–1071 .

[3] B. Williams , P. Durvasula , D. Brown , Urban freeway traffic flow prediction: application of seasonal autoregressive integrated moving average and expo- nential smoothing models, Transp. Res. Rec. J. Transp. Res. Board 1644 (1998) 132–141.

[4] K.-R. Müller , A.J. Smola , G. Rätsch , B. Schölkopf , J. Kohlmorgen , V. Vap- nik , Predicting time series with support vector machines, in: Proceedings of the International Conference on Artificial Neural Networks, Springer, 1997, pp. 999–1004 .

[5] MPNG. (2018), "Conservation of petroleum products", Ministry of Petroleum & Natural Gas, Government of India, http://petroleum.nic.in/conserv.html

[6] H.Wang , D.Hu , Comparison of svm and ls-svm for regression, in: Proceedings of the International Conference on Neural Networks and Brain, ICNN&B'05., 1, IEEE, 2005, pp. 279–283 .

[7] Barbosa-Filho, N.H., Taylor, L., 2006. Distributive and demand cycles in the US Economy - A structuralist Goodwin model. Metroeconomica. 57(3), 389-411.

[8] Dávila-Fernández, M.J., Sordi, S., 2019. Distributive cycles and endogenous technical change in a BoPC growth model. Economic Modelling. 77, 216-233.

[9] Goodwin, R., 1967. A growth cycle, in: Feinstein, C.H. (Eds.), Socialism, Capitalism and Economic Growth. Cambridge University Press, Cambridge, 54-58.

[10] Keen, S., 2013. A monetary Minsky model of the Great Moderation and the Great Recession. Journal of Economic Behavior & Organization, 86, 221-235.

[11] Keen, S., 1995. Finance and economic breakdown: modeling Minsky's financial instability hypothesis. Journal of Post Keynesian Economics, 17(4), 607-635.

[12] King, C.W., Menon, B.G., 2018. A long-term growth model with endogenous biophysical and economic states. 36th USAEE/IAEE North American Conference, United States Association for Energy Economics, Washington DC.

[13] Sterman, J.D., 2000. Business Dynamics: Systems Thinking and Modeling for a Complex World, McGraw Hill, New York.

[14] Tavani, D., Zamparelli, L., 2015. Endogenous technical change, employment and distribution in the Goodwin model of the growth cycle. Studies in Nonlinear Dynamics and Econometrics. 9(2), 209-226.