

## India's GDP Growth from 1971-71 to 2019-20: A Semi-Logarithmic Polynomial Analysis

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### Abstract

This study analyses the long-term growth pattern of India's economy by examining its logarithmic GDP (LN-GDP) from 1970–71 to 2019–20. The analysis begins with a linear trend regression, which reveals a consistent annual growth rate of 5.52%, explaining 99.04% of the variation in LN-GDP, indicating steady economic growth over the period. The quadratic model improves upon this with an  $R^2$  of 0.9991 with higher adjusted R square, showing that the economy's growth has accelerated over time. Moving to the cubic regression, which further refines the fit with an  $R^2$  of 0.9994, we observe a slight deceleration in growth, as indicated by the negative cubic term. Higher-order polynomial regressions (degree four to six) continue to improve the model fit, but the significance F values and the  $R^2$  indicate diminishing returns with the addition of more terms. While the fifth-degree model yields the highest adjusted  $R^2$ , the cubic model remains the best fit based on its low significance F value. The higher-order polynomial functions confirm that India's GDP growth is nearly cubic in nature.

**Keyword:** India's Economic Growth, Logarithmic GDP, Cubic Trend Regression, Growth Rate Analysis

**JEL Classification:** O47, E01

### Introduction

The evolution of economic systems is a dynamic and continuous process that has shaped the trajectory of human civilization. From the early stages of subsistence hunting and gathering to the advent of agriculture, industrial manufacturing, and the modern service-oriented economies, the nature of economic activity has undergone transformative shifts. These transitions have been driven by humanity's growing aspirations and the relentless pursuit of improved standards of living, facilitated by technological advancements that have revolutionized production processes and expanded the scale of economic output.

Economic growth lies at the heart of this evolutionary process, serving as a critical indicator of any nation's progress and development. It encompasses the expansion of economic activity, the creation of wealth, and the improvement of societal well-being. A robust and sustained economic growth trajectory can enhance living standards, provide better access to healthcare, and improve educational opportunities. Furthermore, it fosters job creation, reduces poverty, and promotes social mobility, enabling a more equitable distribution of resources and opportunities.

India makes a strong stable and long-term economic growth since from post independent era. Its economic trajectory from 1970–71 to 2019–20 clearly reveal the picture of a time of significant change by globalisation, technological advancements, new economic policy and structural reforms. This study analyses India's economic growth pattern during this time using natural logarithmic GDP (LN-GDP). It provides significant and meaningful on the wider implications for steady economic growth by revealing the nature and drivers of growth through linear regression method.

### **Literature Review**

In developing nations like India, growth of GDP exponential in nature which causes polynomial trend models namely, quadratic, cubic, Quartic, Quintic, Sextic and other higher order polynomial regressions are frequently used to analyse long-term economic growth. There has been a growing emphasis on using polynomial functions in models of economic growth, particularly when taking transitional dynamics into account. The most of the country's GDP may not linear due to several ups and downs arise from police change by the government or fluctuations arise from natural calamities or some other reasons. According to Lucke (2002), Germany's GDP catch-up following World War II cannot be properly explained by a simple linear trend model, this means polynomial trends in unit root tests are preferable. The higher-order polynomial function section suggests that, due to World War II, the growth path may not be linear (first-degree) in nature; instead, a higher-degree polynomial function might provide a better fit. This approach is in consistent with other studies that look at non-linear growth patterns. Guillén and Rodríguez (2014) examine a non-linear decomposition method for Peruvian GDP with the objective to detect structural changes in productivity. Their approach enhances polynomial higher order function capacity to clearly represent economic trends, despite the fact that they are not especially concerned with polynomial growth. Mayazir and Jahufer (2016) use polynomial distributed lag models to investigate how different macroeconomic factors affect Sri Lanka's economic growth. Their findings show how different factor play very important role, namely, investment, FDI, and spending are to growth of the economy. Bhowmik (2020) uses many different types of higher order poly nominal function methods to analyse and capture different types of fluctuations, namely seasonal and cyclical fluctuations in the growth of the economy in Ukraine in order to understand the trends and fluctuations. The study validates V-shaped seasonal fluctuations in GDP and emphasises the importance of using polynomial models to analyse economic cycles. Using statistical data analysis and polynomial trend models, Pyra and Siedlecka (2022) examine the negative correlation between inflation and economic growth, confirming the long-term benefits of low inflation on economic growth. In 2023, Bouzmit et al. attempted to identify the various effects of energy consumption and human capital. Research employing cointegrating polynomial regressions, like this Algerian study, shows that human capital plays two roles: it directly lowers energy demand while also indirectly raising it through income and tangible assets. Results consistently refute the E-EKC hypothesis, demonstrating that economic expansion drives emissions and energy consumption. One way to achieve sustainable growth is to invest in education and renewable energy. To forecast GDP growth in China's regions, Ning, He, Zeng, Mei, and Cang (2023) suggest a matrix model that combines exponential and polynomial functions. They show that this method outperforms other models in terms of forecasting performance.

Therefore, polynomial regressions offer a reliable way to comprehend the changing course of India's GDP growth, providing information that more straightforward models might overlook.

Even though they are more complicated, higher-order models greatly increase the precision of growth trend forecasts.

### Objectives

- To estimate both the linear and higher-order trend growth patterns of India's Gross Domestic Product (GDP).

India's GDP has grown steadily over the last 50 years (1970–71 to 2019–20), there is no doubt growth of GDP very directly related to economic development of any nation. Policymakers need to be able to accurately measure GDP growth trends in order to create long-term economic policy by the government and several strategies related to macroeconomic development.

This study's main goal is to properly identify the average annual growth rate of India's GDP. The study also investigates the application of higher-order polynomial functions in a semi-logarithmic framework to more accurately evaluate growth trends. At the end, we try to determine which polynomial model best fits the observed GDP data for India.

### Data Sources

The data for India's Gross Domestic Product (GDP) is sourced from the *RBI Handbook of Statistics* (2023). The figures are presented in constant prices, using the 2011-12 base year. The values are measured in crores of rupees.

### Methodology

Since economic growth is so important to advancing societal welfare, it continues to be a central topic in modern economics. It is essential for increasing markets, creating jobs, and raising living standards. Economic growth is therefore crucial to comprehend and measure for researchers, policymakers, and economists alike.

A popular method for assessing economic growth is to calculate the compound growth rate over time of a pertinent indicator, like GDP. This rate represents a variable's steady exponential growth over a given period of time. However, it is not appropriate to assume uniform growth over the entire period because growth trends frequently deviate from a constant path. Economists commonly use trend regression models, which more accurately depict shifting growth patterns over time, to address this problem.

Typically, growth in time series data is analyzed using a semi-logarithmic linear regression model, which can be represented as:

$$\ln Y_t = a + bt + et \dots \dots \dots (1)$$

It helps to analyse this model's components in order to understand its mechanics. The natural logarithm of the observed value, represented as  $\ln(Y_t)$ , is the dependent variable, and 't' stands for the time period. The regression equation's coefficient 'b' represents the steady growth rate. The model's random disturbances are taken into account by the error term, et, which is assumed to have a normal distribution with a mean of zero and constant variance.

Applying a logarithmic transformation to the dependent variable provides several benefits. It effectively captures the exponential character of economic growth often seen in empirical

data, minimizes issues related to heteroscedasticity (non-constant variance), and simplifies the interpretation of the coefficient 'b', which directly reflects the growth rate.

To estimate the Compound Annual Growth Rate (CAGR), the same regression model is utilized, and the growth rate is computed using the formula:

$$\text{Growth rate} = (\exp(b) - 1) \times 100$$

Here, 'exp' denotes the exponential function (i.e., the antilog), and 'b' is the estimated coefficient representing the exponential growth rate.

Note that b in equation (1) is the slope of regression line  $\frac{d\ln(Y_t)}{dt}$  and it is assumed to be constant. However, if the growth rate is not constant and is either increasing or decreasing over time, we can use a log quadratic (polynomial of order/degree 2) equation. The log quadratic equation can be written in the form:

$$\ln(Y_t) = a + bt + ct^2 \quad \dots \quad \dots \quad \dots \quad (2)$$

so that the growth rate  $\frac{d\ln(Y_t)}{dt} = b + 2ct$  becomes a function of t. Thus, if  $Y_t$  is increasing or if it exhibits positive growth throughout the period, or at least in the initial period, the value of 'b' becomes positive, whereas the value of 'c' may be positive or it may be negative depending upon whether the growth rate is increasing (i.e., accelerating) or decreasing (i.e., decelerating) respectively over the period of time. Therefore, if both 'b' and 'c' are positive, we have positive growth with acceleration. Actually, the path of  $\ln(Y_t)$  in the extended period becomes U-shaped or strictly convex with a minimum point at some value of time (t). But if 'b' is positive and 'c' is negative we have initial positive growth with deceleration. If this deceleration is strong enough, may lead to negative growth after some period of time. Here, the path of  $\ln(Y_t)$  in the extended period takes the shape of an inverted-U or strictly concave with a maximum point at some value of time (t). The minimum or maximum is found where  $\frac{d\ln(Y_t)}{dt} = b + 2ct$  becomes zero, or at  $t = -\frac{b}{2c}$ . Note that we shall take a log quadratic equation in place of a log linear equation only if this latter equation gives a better fit in comparison to the former.

Moreover, if the growth rate is not increasing or decreasing throughout, we can use a log cubic (or, polynomial of order/degree 3) or polynomial of order/degree greater than 3. If we take a log cubic equation, it takes the form:

$$\ln(Y_t) = a + bt + ct^2 + dt^3 \quad \dots \quad \dots \quad \dots \quad (3)$$

and the growth rate  $\frac{d\ln(Y_t)}{dt} = b + 2ct + 3dt^2$  becomes a quadratic function of t. Now, assuming a positive initial growth 'b' becomes positive, and the values of 'c' and 'd' determine the nature of change in the growth path in the subsequent periods. If both 'c' and 'd' are positive along with positive 'b', the growth will increase at an increasing rate than that implied by equation (2) with both 'b' and 'c' positive. Here, the path of  $\ln(Y_t)$  will be convex, but a minimum may not exist. Similarly, if both 'c' and 'd' are negative and 'b' is positive, the growth will be decreasing at decreasing rate than that implied by equation (2) with 'b' positive and 'c' negative. Here, the path of  $\ln(Y_t)$  will be concave, but a maximum may not exist. Finally, with 'b' remaining positive, if 'c' and 'd' are of opposite signs, the growth will be neither accelerating nor decelerating throughout. If 'c' is positive and 'd' is negative, it will be initially accelerating but ultimately decelerating. Or, the path of  $\ln(Y_t)$  will be initially convex and ultimately concave and may have a minimum in the convex phase and a maximum in the concave phase, if they at all exist. The opposite will be the case if 'c' is negative and 'd' is positive. Or, the path of  $\ln(Y_t)$  will be initially concave and ultimately convex and may have a minimum and a maximum, if they at all exist. In both the cases, the first phase will be continued up to the point of inflection where  $\frac{d^2\ln(Y_t)}{dt^2} = 2c + 6dt$  is zero, or

$t = -\frac{c}{3d}$ . Note that we shall take a log cubic equation in place of a log quadratic equation only if this latter equation gives a better fit in comparison to the former. In this way, if a polynomial equation of order/degree 4 gives a better fit than that of order/degree 3, we shall have two inflection points, or the change in curve will curvature twice, either from convex to concave and then again to convex, or from concave to convex and then again to concave; and so on. Note that the use of higher order/degree polynomial helps us explaining a part of fluctuations and break in the growth path. The fluctuation is mainly cyclical in nature. These estimated cycles are basically long cycles which seem to be created through policy changes and they fail to address business cycles, year to year and irregular fluctuations. These cycles being smooth and well behaved may not always be able to address non-smooth breaks created through policy changes. In those cases, we have to think of other methodologies because only linear or higher-order economic growth may fail to give a true picture of an economy. We also need to identify other factors, such as structural breaks in the linear growth path or fluctuations around the trend linear growth path, for a comprehensive understanding of an economy.

### Results and Discussions

This section presents the annual average growth rate of India’s GDP over the 50-year periods from 1970–71 to 2019–20.

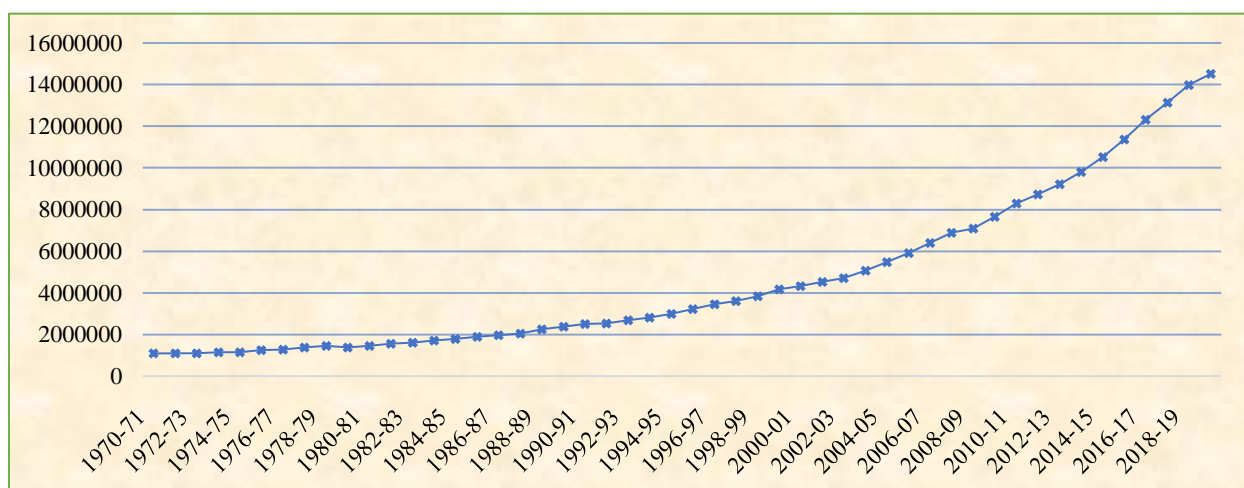
India has achieved the status of being the economy with the highest rate of growth in the world. India has consistently achieved strong economic growth in its GDP during the last several decades, leading to an increase in per capita incomes and also helping to reduce the absolute poverty rate. Here, we figure out the current trend linear growth scenario of India’s GDP.

#### The nature of the growth in India’s Gross Domestic Product

Figure 1 shows that the growth of India’s GDP is exponential in nature (common nature of almost all time series variables).

**Figure 1: Exponential trend in India’s GDP over the period 1970–71 to 2019–20.**

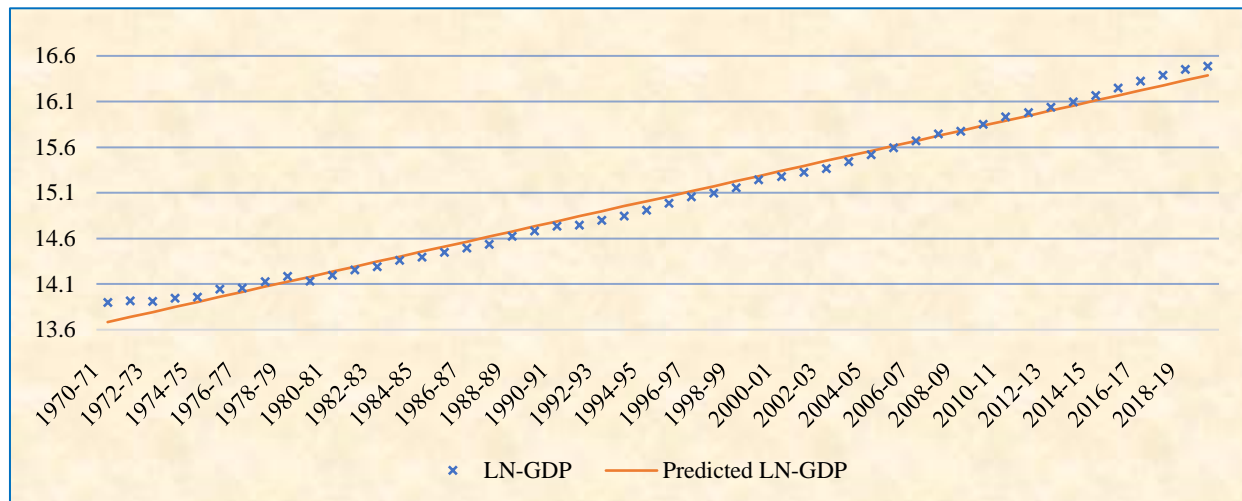
Source: own calculation



To estimate the Exponential Annual Growth Rate (EAGR), the natural logarithm of India’s GDP was regressed on the time variable (t). The trend analysis of India’s GDP from 1970–71 to 2019–20 (as illustrated in Figure 2) reveals a generally upward trajectory, indicating

sustained economic growth during the period. Despite some fluctuations, the logarithmic transformation of GDP exhibits a linear pattern, with the fitted trend line suggesting a stable and positive growth rate over time.

**Figure 2: Log-transformed GDP data of India with corresponding linear trend line (1970–71 to 2019–20)**



Source: own calculation

Based on the results presented in Table 1, the estimated average annual growth rate stands at 5.52%. The regression analysis demonstrates a high degree of model fit, with an R-squared value of 0.9904 and an adjusted R-squared of 0.9902. The F-statistic is 4969.75, accompanied by a highly significant p-value of 4E-50. This implies that only 0.96% of the variation in the natural logarithm of GDP remains unexplained by the model (since  $1 - R^2 = 0.0096$ ). The plot of the log-transformed GDP values in Figure 4.6.1 further illustrates noticeable fluctuations over the observed period.

**Table 1: Estimated results from the trend regression of India’s log-transformed GDP (1970–71 to 2019–20)**

	Coefficients	R Square	0.9904
Intercept	13.6281	Adjusted R Square	0.9902
Time (T)	0.0552	Standard Error	0.0799
F value	4969.75	Significance F	4E-50

Source: Own calculation

Upon thorough examination of the figure, it becomes evident that there are fluctuations present alongside the linear trend (constant growth) path. Following a closer look at figure 2, it becomes apparent that the fluctuations mostly arise from the deviation of the path from the linear trend line. Thus, if we fit a log quadratic equation (polynomial of order/degree two), the estimated equation becomes

$$\ln(\text{GDP}) = 13.8046 + 0.0348t + 0.00034t^2 \dots \dots \dots (4)$$

The equation obtained from quadratic equation 2. Equation 4 shows the growth rate increasing at an increasing rate in the quadratic equation. We tried to find a higher-order polynomial function up to a six-degree polynomial function to find out the true nature of the growth of India’s GDP. Therefore, the growth rate  $\frac{d\ln(Y_t)}{dt} = b + 2ct$  becomes a function of t. Both ‘b’ and ‘c’ are positive, we have positive growth with acceleration. Actually, the path of  $\ln(Y_t)$  in the extended period becomes U-shaped or strictly convex with a minimum point at

some value of time (t). As both ‘b’ and ‘c’ are positive, they have a minimum point, and the minimum is observed in the years 1926–27, which is beyond our study period. Table 2 presents the results of regression on higher order polynomial function. We do up to a six-degree polynomial function (sextic function).

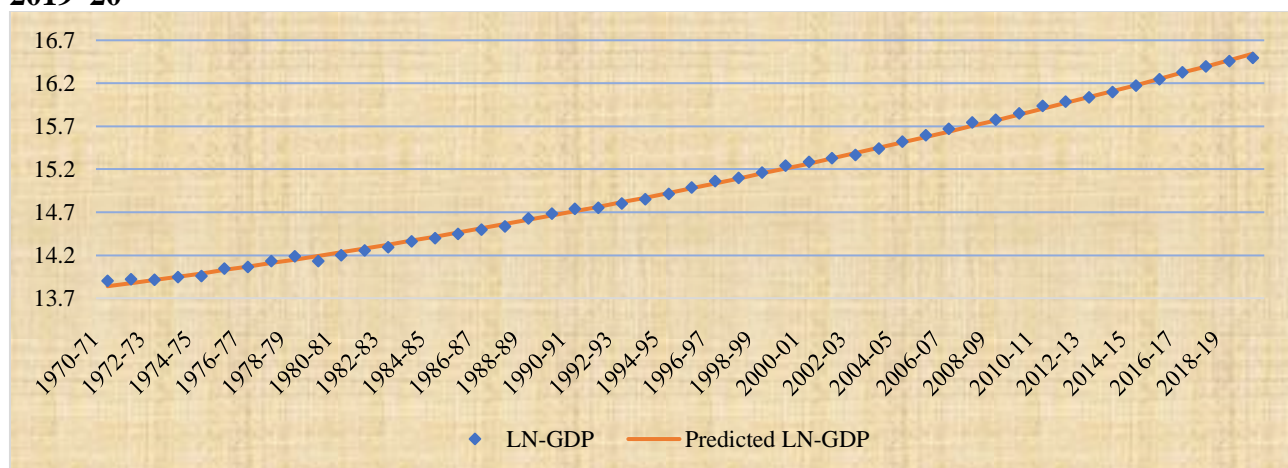
**Table 2: Comparison of linear and polynomial trend regressions applied to India’s log GDP data (1970–71 to 2019–20)**

GDP								
Linear			Linear	Quadratic	Cubic	Degree four	Degree five	Degree Six
	<i>Coefficients</i>	R Square	0.9904	0.9991	0.9994	0.9994	0.99943	0.999429
Intercept	13.6281	Adj- R Square	0.9902	0.9990	0.99935	0.99934	0.99936	0.99935
Time (T)	0.0552	F-Value	4969.75	25099.63	25027.79	18656.41	15411.25	12552.36
		Sig- F	3.97E-50	6.58E-72	6.92E-74	8.36E-72	3.68E-70	4.82E-68

Source: Own calculation

The Table 2 shows the adjusted R square is second highest at third degree (Cubic) polynomial function with significance F-value. The results of degree five show the adjusted R square highest, but on the basis of the lowest significant F-value, we determined that the economic growth path of India’s GDP is nearly cubic in nature.

**Figure 3: Quadratic trend representation of India’s log GDP data from 1970–71 to 2019–20**



Source: Own calculation

The quadratic trend regression analysis of India’s logarithmic GDP (LN-GDP) for the period 1970-71 to 2019-20 reveals a strong and statistically significant relationship between time and economic growth. The intercept coefficient of 13.8046 represents the baseline value of the logarithmic GDP at the start of the period (1970-71). The linear term coefficient (0.0348) suggests a positive growth trend over time, indicating that India's economy has experienced consistent expansion. Furthermore, the quadratic term coefficient (0.0004) reveals that the growth rate of India’s GDP has accelerated, as the positive sign indicates an upward curvature in the GDP trend, reflecting an increasing rate of growth over the decades. The p-values for

both the linear (4.8E-35) and quadratic (9.8E-12) coefficients are extremely small, confirming that these relationships are statistically significant. The R<sup>2</sup> value of 0.9991, along with the adjusted R<sup>2</sup> of 0.9990, indicates that the model explains nearly all the variations in LN-GDP, underscoring the robustness of the model. Additionally, the high F-statistic of 25099.6 and the extremely low significance F-value of 6.6E-72 further support the overall validity and significance of the regression model, demonstrating its effectiveness in capturing the long-term growth trend of India's economy.

**Table 3: Estimated results from the quadratic trend regression of India's LN-GDP (1970–71 to 2019–20)**

	<i>Coefficients</i>	<i>P-value</i>	R Square	0.9991
Intercept	13.8046	9.9E-108	Adjusted R Square	0.9990
T	0.0348	4.8E-35	<i>F</i>	25099.6
T <sup>2</sup>	0.0004	9.8E-12	<i>Significance F</i>	6.6E-72

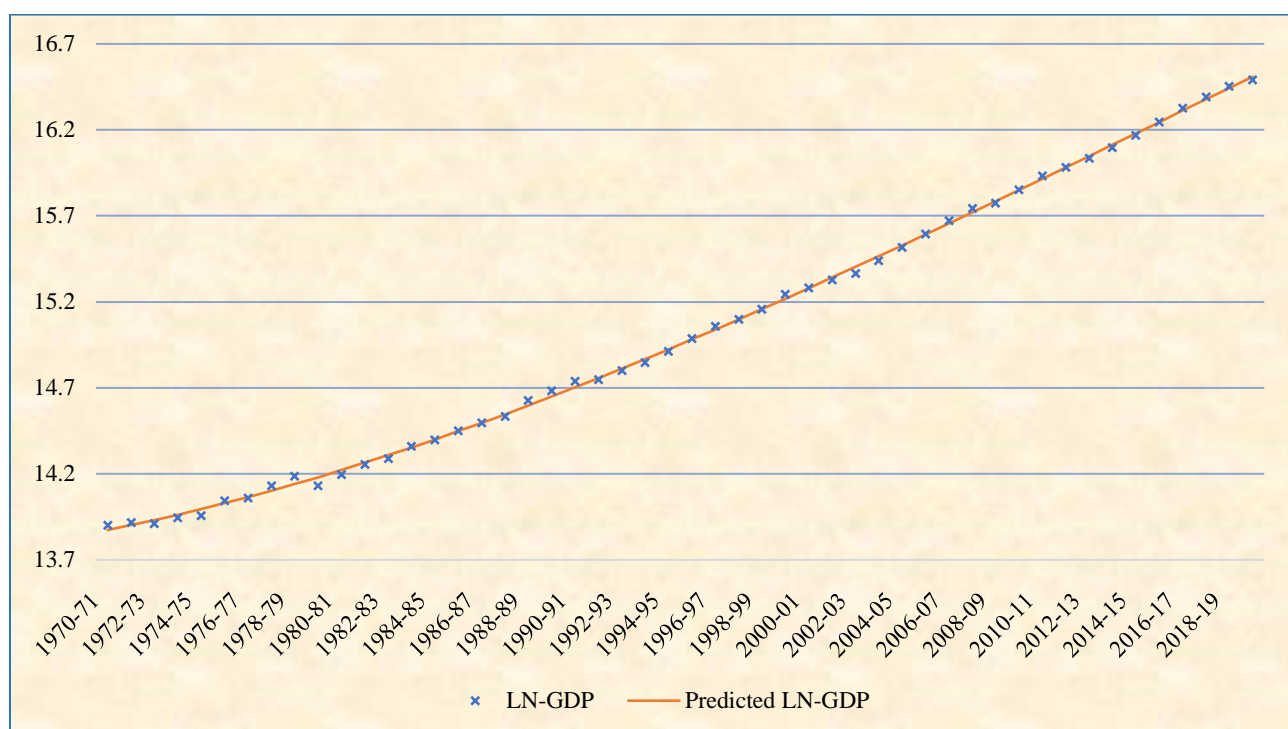
Source: Own calculation

After examining the quadratic trend regression, which captures the general growth pattern of India's LN-GDP, we move to the cubic trend regression to explore a more nuanced relationship. The cubic model introduces an additional term (T<sup>3</sup>), allowing for the possibility of changes in the acceleration and deceleration of growth over time, offering a more flexible fit to the data. So, in Figure 4 and Table 4, we have attempted to present the detailed findings of the cubic growth path of India's GDP. If a log cubic model (polynomial of order/degree three) is fitted, the estimated equation becomes:

$$\ln(\text{GDP}) = 13.847 + 0.0252t + 0.0009t^2 - 6.1E-06t^3. \dots \dots \dots (5)$$

Equation 5 is calculated based on equation 3 in the methodology section. Equation 5 shows growth path becomes a convexo concave line. Figure 4 also presents India's GDP nature convexo concave type.

**Figure 4: Log-transformed GDP data of India with cubic trend line (1970–71 to 2019–20)**



Source: Own calculation

Table 4 presented that the R-square is 99.94 percent with a high significance F-value. The coefficients of T, T<sup>2</sup>, and T<sup>3</sup> are also significant, which indicate that the growth path is approximately cubic in nature. From the estimated cubic path, the growth path is estimated as  $\frac{dln(Y_t)}{dt} = 0.0252 + 0.0017t - 1.8E-05t^2$ .

The growth rate  $\frac{dln(Y_t)}{dt} = b + 2ct + 3dt^2$  becomes a quadratic function of t. If 'c' is positive and 'd' is negative, along with the positive 'b', it will initially accelerate but ultimately decelerate. At the initial convex phase in the year 1926-27  $[(-b/2c)]$ , the growth rate was 2.69%. the path of ln(Y<sub>t</sub>) was initially convex and ultimately concave and have a maximum in the convex phase at the year 2017-18  $[(-c/3d)]$  where growth rate was 6.62%, and lastly it continue at concave phase and in the year 2019-20 the growth rate was 6.60%.

**Table 4: Estimated coefficients from the cubic trend regression of India's LN-GDP (1970-71 to 2019-20)**

	<i>Coefficients</i>	<i>P-value</i>	R Square	0.9994
Intercept	13.8475	2.7E-103	Adjusted R Square	0.9993
Time (T)	0.0252	1.3E-15	Standard Error	0.0206
T <sup>2</sup>	0.0009	9.8E-12	F-Value	25027.8
T <sup>3</sup>	-6.1E-06	1.1E-05	Significance F	6.9E-74

Source: Own calculation

Estimation of trend growth rates by fitting polynomials of different orders/degrees is no doubt a good method. However, it is important to note that this approach may not always provide accurate estimates because of the fitting of smooth curves.

The cubic trend regression of India's LN-GDP for the period 1970-71 to 2019-20 shows a highly significant model with an even better fit compared to the quadratic model. The intercept (13.8475) is similar to the quadratic model, indicating a comparable baseline value

for GDP at the start of the period. The linear term coefficient (0.0252) is lower than in the quadratic model (0.0348), reflecting a slower initial growth rate. The quadratic term (0.0009) and cubic term (-6.1E-06) suggest that the growth rate initially increased but then slightly decelerated over time, as indicated by the negative cubic coefficient. With an  $R^2$  of 0.9994 and an adjusted  $R^2$  of 0.9993, the cubic model explains an even higher proportion of the variation in LN-GDP than the quadratic model. The low p-values and F-statistic (25027.8) again confirm the statistical significance and robustness of the cubic regression model.

### **Conclusion:**

This research examines India's economic growth from 1970–71 to 2019–20 through various trend regression models applied to LN-GDP. The linear regression model reveals a steady 5.52% annual growth rate, reflecting consistent expansion in the Indian economy over the period. The quadratic regression model improves the fit with an  $R^2$  of 0.9991, showing an acceleration in growth, driven by structural transformations in India's economy.

The cubic regression model, which introduces an additional layer of complexity, reveals that the growth rate may have slightly decelerated in more recent years, as evidenced by the negative cubic term. This subtle deceleration suggests that while India's economy continues to grow, the rate of growth may be moderating due to factors such as global economic conditions, domestic policy constraints, or maturing industries. The  $R^2$  for the cubic model (0.9994) indicates an almost perfect fit, which is further reinforced by a very low p-value and a high F-statistic of 25027.79, highlighting the robustness of the model.

Further extensions to higher-order polynomial models, such as degree four to degree six, provide increasingly refined fits, but the significance F-values show diminishing marginal benefits. Although the fifth-degree model has the adjusted R square, the improvements in fit are marginal compared to the cubic model. The cubic model, while simpler, remains the best choice due to its balance between predictive accuracy and statistical robustness, as evidenced by its Significance F value, adjusted R square and  $R^2$ . Thus, despite the theoretical potential of higher-order models, the cubic model emerges as the most effective for capturing India's economic growth trajectory.

This research offers valuable insights for policymakers and economists, as the cubic model provides a clear understanding of the evolving nature of India's economic growth. While the models demonstrate strong predictive power, further studies could explore external variables such as global economic factors, technological advancements, and policy changes to enhance the understanding of India's growth dynamics in the future.

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