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Forecasting the Consumer Price Index in Banyumas Regency Using Double Exponential Smoothing with Proportional Integral Derivative Controller

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Abstract. The Consumer Price Index (CPI) serves as a vital indicator of inflation and the cost of living within a given region. Accurate CPI forecasts are indispensable for policymakers, businesses, and stakeholders to make informed decisions. This study employs the Double Exponential Smoothing (DES) method to forecast the CPI for Banyumas Regency in September 2025, utilizing monthly CPI data from January 2020 to August 2025, sourced from secondary data available on the official website https://banyumaskab.bps.go.id/id. The DES method was chosen due to the observed upward trend in historical CPI data prior to the application of the Proportional Integral Derivative (PID) controller. Python programming was utilized to optimize the smoothing parameters α and β, and the results were evaluated using Mean Absolute Deviation (MAD), Mean Squared Error (MSE), Mean Absolute Percentage Error (MAPE), and Mean Absolute Scaled Error (MASE). The forecasted CPI for September 2025 is 107.61, with high accuracy indicators, including a MASE of 0.15%, demonstrating that DES with PID controller is a reliable model for CPI forecasting in Banyumas Regency.

Keywords: *Consumer Price Index (CPI); Forecasting; Double Exponential Smoothing (DES); Proportional Integral Derivative (PID) Controller, Inflation; Time Series; Forecast Accuracy.*

1 Introduction

Inflation is a vital macroeconomic indicator that affects consumer purchasing power, the stability of both regional and national economies, and the efficacy of fiscal and monetary policies. The Consumer Price Index (CPI) serves as a primary measure for evaluating inflation, representing the average price changes of a standard basket of goods and services acquired by households over time [1], [2].

Accurate forecasting of the CPI is crucial for the formulation of government policies, business decision-making, and the implementation of social welfare programs. In regional contexts, such as Banyumas Regency, where the economy is significantly influenced by sectors including tourism, agriculture, and services, fluctuations in the CPI can substantially affect local development outcomes [3]. Given the increasing complexity of

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regional price movements, forecasting tools capable of modeling trend-based time series data are indispensable [4].

Forecasting involves predicting future values by analyzing historical data. Among quantitative forecasting methods, time series analysis has demonstrated its effectiveness in various economic contexts, particularly when dealing with data that exhibit trends and seasonal patterns [5]. The Double Exponential Smoothing (DES) technique, also referred to as Holt's linear method, is especially appropriate for data displaying linear trends, as it incorporates two components: level and trend smoothing [6].

Recent studies have increasingly employed DES to tackle challenges in economic and inflation forecasting. [4] demonstrated that DES outperforms other exponential methods in modeling the CPI in East Kalimantan. Similarly, [7] utilized DES to forecast retail prices, reporting very low mean absolute errors, which highlights the method's reliability. Furthermore, contemporary implementations using Python and R have facilitated parameter optimization, thereby enhancing model fitting [8].

Previous research predominantly employed DES in isolation, without the integration of advanced control methodologies. Nevertheless, the incorporation of a Proportional Integral Derivative (PID) controller presents the potential to enhance accuracy by rectifying forecast errors in real-time [9]. This methodology enables the model to adapt more effectively to trend fluctuations and price anomalies. This study introduces a novel approach by applying a PID controller to each data point generated from DES forecasting, thereby minimizing error and augmenting the reliability of Consumer Price Index (CPI) predictions for Banyumas Regency. The choice of DES in conjunction with a PID controller is predicated on its capacity to manage linear trend data while automatically adjusting for deviations in forecast outcomes, rendering it suitable for regional price dynamics [10].

In recent years, Banyumas Regency has witnessed consistent economic growth, driven by an increase in tourism and urban development. According to BPS data (2025), the region's CPI has shown a steady rise from 2020 to 2025. This trend positions the area as an ideal candidate for CPI forecasting utilizing DES with a PID controller.

Predicting inflation at a regional level is crucial for economic planning, particularly in regions experiencing rapid growth in sectors such as tourism, trade, and local consumption. Recent research has highlighted the utility of time series models, particularly smoothing techniques, in forecasting economic indicators like inflation and the CPI. [11] demonstrated that smoothing models are effective in predicting local food inflation, providing essential insights for stabilizing food prices in regions susceptible to volatility. Similarly, [12] employed time series decomposition and DES to estimate urban cost indexes, illustrating that these models can accurately reflect real economic conditions when data is appropriately adjusted. These insights are especially relevant for rapidly developing areas such as Banyumas Regency, where precise short-term forecasts can assist policymakers in alleviating inflationary pressures and safeguarding consumer purchasing power.

Furthermore, the integration of computational tools such as Python has significantly expanded the scope and precision of forecasting models. [13] employed smoothing-based time series forecasting in the analysis of the public sector, underscoring the utility of automated modelling for the development of real-time policies. In a similar vein, [14] identified that smoothing techniques, particularly Double Exponential Smoothing (DES), were notably effective for short-term inflation forecasting due to their responsiveness to recent data trends. Building upon this foundation, [15] incorporated Python programming into regional forecasting models to enhance both speed and precision, thereby facilitating data-driven decision-making processes. Additionally, [16] applied Holt's method for CPI forecasting across Indonesian provinces, achieving high predictive accuracy. [17] further emphasized the necessity of evaluating forecasting accuracy using metrics such as Mean Absolute Deviation (MAD), Mean Squared Error (MSE), Mean Absolute Percentage Error (MAPE), and Mean Absolute Scaled Error (MASE) to ensure model reliability across various economic contexts. These advancements underscore the importance of DES as a practical forecasting tool, particularly when combined with computational optimization techniques for monitoring regional inflation.

This study aims to analyze the CPI data for Banyumas Regency from January 2020 to August 2025, with the objective of forecasting the CPI for September 2025 utilizing the DES technique with a PID controller. Furthermore, the research evaluates the accuracy of the forecast by employing standard error metrics, including MAD, MSE, MAPE and MASE. The insights gained from the forecast are intended to support regional economic planning and decision-making. Ultimately, the findings are expected to contribute to the existing literature on regional economic forecasting and offer practical guidance for managing inflation and formulating strategic policies at the local government level.

2 Mathematical Formulation

The DES technique is a forecasting method for time series data that accounts for temporal trends. In contrast to single exponential smoothing, which solely adjusts the series' level, DES incorporates two primary components: the level (or smooth value) and the trend. This enables it to more accurately capture upward or downward shifts in the data. This method is particularly advantageous when the time series exhibits linear trends and is not significantly affected by seasonal variations [18].

In mathematical terms, the DES method utilizes two smoothing parameters: α, which determines the degree of smoothing for the level component, and β, which governs the smoothing for the trend component. These parameters assume values ranging from 0 to 1. The smoothing process involves three primary equations: one for updating the level estimate, another for the trend estimate, and a third for generating the forecast.

The first equation, which updates the level component, is given by [19]:

$$S_t = \alpha X_t + (1-\alpha)(S_{t-1} + b_{t-1}),$$

where:

S_t is the estimated level at time t,

X_t is the actual observed value at time t,

S_{t-1} is the previous level estimate, and

b_{t-1} is the previous trend estimate.

The second equation updates the trend component and is defined as [20]:

$$b_t = \beta(S_t - S_{t-1}) + (1-\beta)b_{t-1},$$

where:

b_t is the trend estimate at time t,

$S_t - S_{t-1}$ is the change in level between the current and previous period.

Together, these two recursive equations allow the DES method to learn and adapt to changes in both level and trend across time. The final forecast for *m* steps ahead is calculated by [19], [21]:

$$\hat{X}_{t+m} = S_t + m.b_t + K_p e_t + K_i \sum_{i=1}^{n} e_i + K_d(e_t - e_{t-1}),$$

where $\hat{X}_{t+m}$ is the forecasted value with PID controller for *m* periods after time t and $e_t = X_t - \hat{X}_t, e_0 = 0, \sum e = e_1, K_p \in [0,1], K_i \in [0,0.1], K_d \in [0,1]$. The value was chosen based on the results of research previously conducted in study [22], which $K_p = 0.94, K_i = 0.2, K_d = 0.4$.

To assess the accuracy of the DES model, several error metrics are typically employed. The Mean Absolute Deviation (MAD) is used to measure the average absolute difference between the actual values and the forecasted values, and is given by:

$$MAD = \frac{1}{n}\sum_{t=1}^{n}\left|X_t - \hat{X}_t\right|,$$

where n is the number of forecasted periods.

The Mean Squared Error (MSE), which gives more weight to larger errors due to squaring, is defined as:

$$MSE = \frac{1}{n}\sum_{t=1}^{n}\left(X_t - \hat{X}_t\right)^2.$$

The Mean Absolute Percentage Error (MAPE) provides a percentage-based evaluation of forecast accuracy, useful for comparisons across datasets or variables with different scales:

$$MAPE = \frac{100\%}{n}\sum_{t=1}^{n}\left|\frac{X_t - \hat{X}_t}{X_t}\right|.$$

The Mean Absolute Scaled Error (MASE) is also selected for error analysis due to its suitability for comparing errors across series with varying scales. It is often more stable than the MAPE, as it is not influenced by zero denominators, and is calculated using the following formula:

$$MASE = \frac{\frac{1}{n}\sum_{t=1}^{n}|e_t|}{\frac{1}{n-1}\sum_{t=2}^{n}|X_t - X_{t-1}|},$$

with $e_t = X_t - \hat{X}_t$.

The DES method provides a robust and adaptable framework for forecasting time series data characterized by a trend, through the integration of specific mathematical components. The selection of appropriate values for the parameters α and β is crucial, as they significantly affect the sensitivity and stability of the forecasts. In this study, these parameters are optimized using Python programming via grid search to minimize forecasting errors, thereby achieving the most accurate prediction for the CPI in Banyumas Regency.

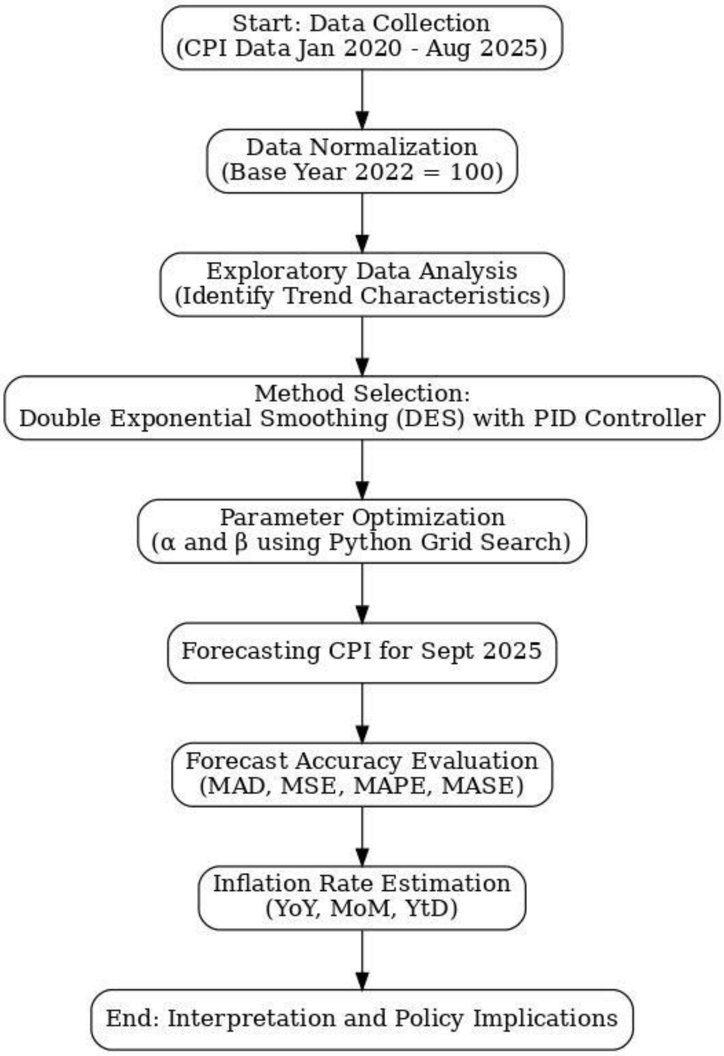

Figure 1. Flowchart Analysis Data

The flowchart depicted in Figure 1 delineates the methodological framework employed in this study to forecast the CPI for Banyumas Regency. The process commences with data collection, utilizing CPI figures from January 2020 to August 2025, followed by data normalization to the base year 2022 (2022 = 100) to ensure temporal consistency. Subsequently, exploratory data analysis is conducted to discern existing trends and characteristics within the dataset. Based on these insights, the DES method, in conjunction with a PID controller, is selected due to its capacity to model linear trends while dynamically correcting forecast deviations in real time.

The subsequent phase entails the optimization of the smoothing constants α and β through the application of Python's grid search technique, with the objective of minimizing forecast errors. Upon determining the optimal parameters, the model advances to forecast the CPI for September 2025. The precision of these forecasts is evaluated using four error metrics: MAD, MSE, MAPE, and MASE. Based on the projected CPI, inflation rates are computed in Year-on-Year (YoY), Month-on-Month (MoM), and Year-to-Date (YtD) terms. Ultimately, the results are interpreted to derive policy implications, providing valuable insights for regional economic planning and inflation management.

3 Result and Discussion

This study utilized monthly CPI data from Banyumas Regency, covering the period from January 2020 to August 2025. All figures were standardized to the base year 2022 (=100) to ensure temporal consistency. Upon normalization, the CPI data demonstrated a distinct upward trajectory, indicating a consistent increase in the inflation rate over the five-year period. This trend warranted the application of the DES method, which is particularly effective for time series data exhibiting a linear trend component.

To effectively implement the Double Exponential Smoothing (DES) with PID controller technique, a grid search method was employed in Python to determine the optimal values for the smoothing parameters α (alpha) and β (beta). These parameters are essential for adjusting the model's sensitivity to recent changes in level and trend. Utilizing Python software, a program was developed to identify the most optimal values of α and β, which were found to be 0.99 and 0.22, respectively. These values minimized the forecasting error, as indicated by the MASE, and ensured stable forecast performance.

Utilizing these optimal parameters, the DES method was employed to compute smoothed values and forecast future CPI. The model predicted the CPI for September 2025 to be 107.61. This projection aligns with the upward trend observed in historical data and corresponds with the seasonal variations typically noted in the months following holidays. A visual comparison of the actual CPI values with those predicted by the DES with PID controller model demonstrated a strong correlation, further validating the model's reliability.

Table 1. Actual CPI vs Forecasted CPI

Mount	Actual CPI	Forecasted CPI
1	92.10	92.10
2	92.64	92.64
3	92.68	93.17
4	92.61	93.11

5	92.79	92.93
6	93.16	93.08
7	92.97	93.47
8	92.86	93.18
9	92.82	92.99
10	92.89	92.92
11	93.25	92.97
12	93.55	93.40
13	93.88	93.73
14	94.03	94.10
15	94.08	94.23
16	94.12	94.25
17	94.30	94.26
18	94.11	94.44
19	94.20	94.19
20	94.31	94.27
21	94.19	94.40
22	94.52	94.23
23	94.89	94.62
24	95.60	95.05
25	96.24	95.87
26	96.27	96.60
27	97.05	96.56
28	98.65	97.44
29	99.27	99.30
30	99.86	99.93
31	100.26	100.50
32	99.82	100.84
33	100.97	100.19
34	100.99	101.49
35	101.30	101.41
36	101.80	101.70
37	102.17	102.22
38	102.49	102.58
39	102.59	102.89
40	102.87	102.92
41	103.09	103.18
42	103.11	103.39
43	103.26	103.35

44	103.27	103.48
45	103.67	103.44
46	103.89	103.89
47	104.28	104.11
48	104.46	104.53
49	104.52	104.70
50	105.16	104.72
51	105.75	105.45
52	105.82	106.11
53	105.66	106.12
54	105.38	105.86
55	105.17	105.48
56	105.11	105.20
57	105.14	105.12
58	105.30	105.15
59	105.54	105.34
60	106.16	105.62
61	106.59	106.49
62	106.04	106.00
63	106.60	106.55
64	107.77	107.70
65	107.27	107.25
66	107.49	107.48
67	107.58	107.50
68	107.60	107.55
69	-	107.61

Table 1 presents a comparative analysis of the actual CPI values and those predicted by the DES method with a PID controller. The dataset commences in January 2020 and extends through September 2025. From this dataset, several error metrics were calculated, including the MAD, MSE, MAPE, and MASE. The computed values are as follows: MAD = 0.26, MSE = 0.21, MAPE = 0.16%, and MASE = 0.15%.

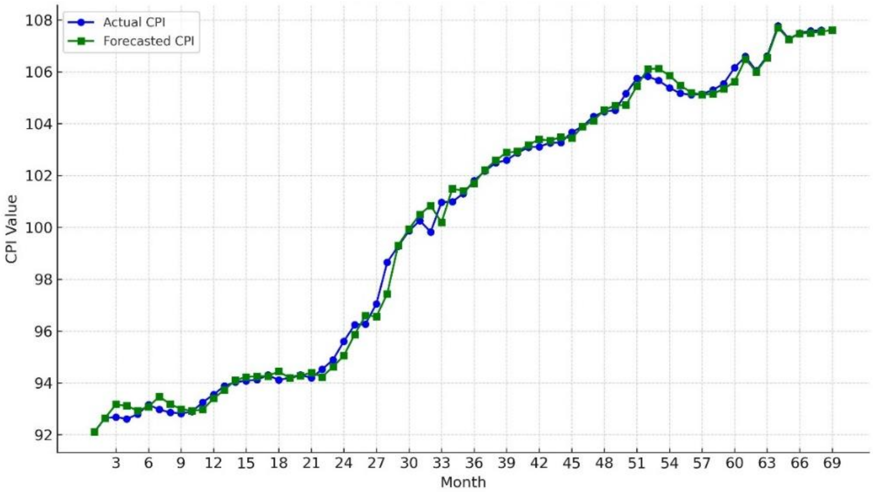

Figure 2. Comparison between the actual CPI values and the forecasted values generated using the DES with PID controller

The Figure 2 above presents a comparative analysis between the actual CPI figures and the predicted values obtained through the DES technique for Banyumas Regency, covering the period from January 2020 to September 2025. The green dashed line, representing the forecasted values, closely aligns with the blue solid line of the actual CPI data, indicating that the DES method effectively captures the upward trend in CPI throughout the observed period. In addition to the forecast, the model's accuracy was evaluated using four standard error metrics: MAD, MSE, MAPE, and MASE. The calculated values were MAD = 0.26, MSE = 0.21, MAPE = 0.16%, and MASE = 0.15%, reflecting high forecast precision and minimal deviation from the actual values. These low error values underscore the DES model's capability to capture the underlying patterns in CPI data and provide robust forecasts with minimal noise.

Based on the projected CPI for September 2025, an analysis was conducted to estimate inflation rates using three standard metrics: YoY, MoM, and YtD. The YoY inflation rate, which compares the anticipated CPI for September 2025 with that of September 2024, was calculated to be 1.99%, indicating a relatively modest increase in consumer prices over the year. The MoM inflation, derived from comparing September 2025 to August 2025, was 0.84%, and the YtD figure—equivalent to the MoM in this instance since January marks the beginning of the year—was also 0.84%.

4 Conclusion

The study illustrates that the DES method, when integrated with a PID controller, proves to be highly effective in forecasting the CPI in Banyumas Regency. By optimizing the smoothing parameters through Python, the model achieved remarkable accuracy, as evidenced by very low error values, including a MASE of 0.15%. The findings suggest that the CPI in September 2025 is anticipated to undergo a moderate increase, closely aligning with historical trends and seasonal patterns. These results offer valuable insights for policymakers in managing inflation and supporting regional economic stability. Moreover, the simplicity, adaptability, and computational efficiency of DES with a PID controller render it a practical forecasting tool that can be replicated in other regions with similar data characteristics. Future research could investigate hybrid approaches or machine learning models to capture more complex dynamics in economic forecasting.

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