Unveiling GDP-FDI Connections via Cubic Regression

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Abstract

This study investigates the relationship between Gross Domestic Product (GDP) and Foreign Direct Investment (FDI) using cubic regression modelling, implemented through Scilab programming. GDP and FDI are critical economic indicators, often interconnected in complex ways. While linear and quadratic models have been traditionally employed to explore their relationship, these models may fail to capture more intricate, nonlinear dynamics. Cubic regression offers a more sophisticated approach that can account for possible fluctuations and inflection points in the data, providing a deeper understanding of how FDI influences GDP over time. In this research, we utilized Scilab, an open-source numerical computation software, to model the relationship between GDP and FDI through cubic regression. The study begins with data collection from Department of Statistics of Malaysia (DOSM) databases. The cubic regression model is then applied to the data, and the results are analysed to interpret the significance of the model's coefficients and the overall fit. Our findings indicate that the cubic regression model better captures the nuances of the GDP-FDI relationship compared to simpler models. Specifically, the cubic term in the regression equation reveals nonlinear patterns that are consistent with economic theory, where FDI impacts GDP differently depending on the stage of economic development or external factors. The model's improved accuracy in fitting the data suggests that policymakers and economists should consider higher-order regression models when analysing the effects of FDI on GDP.

***Keywords**: Cubic regression, Gross domestic product, Foreign Direct Investment, Scilab, Economic modelling.*

1.0 Introduction

Data analysis plays a critical role across disciplines such as economics, biology, and engineering, serving as the cornerstone for uncovering relationships between variables and forecasting future trends. Among the key techniques in this process are regression methods, with both linear and nonlinear regression standing out as fundamental tools. These approaches enable researchers to model complex relationships between independent and dependent variables, providing a robust framework for predictions and informed decision-making. This literature review delves into the theoretical foundations, practical applications, and inherent limitations of linear and nonlinear regression, drawing on a wide range of academic sources to support the discussion.

The intricate relationship between Gross Domestic Product (GDP) and Foreign Direct Investment (FDI) is pivotal in comprehending the mechanisms behind economic growth. FDI is frequently regarded as a fundamental driver of development, facilitating capital inflows, technological advancements, and employment opportunities. However, the influence of FDI on GDP is not uniformly linear. Early research typically employed linear or quadratic models, potentially failing to capture the more complex, nonlinear characteristics of this relationship. To address these limitations, this paper introduces cubic regression as a more robust analytical framework, which can accommodate potential inflection points and dynamic shifts in the GDP-FDI nexus. The implementation of cubic regression using Scilab, an open-source computational tool, ensures that this methodology remains accessible and replicable for researchers and policymakers alike.

Exploring the GDP-FDI dynamic is critical for policymakers aiming to foster economic expansion (Joo & Shawl, 2023). Numerous studies underscore FDI's role as a catalyst for GDP growth, particularly in emerging markets (De Mello, 1997; Borensztein et al., 1998; Joo & Shawl, 2023), with many utilizing linear regression models to quantify this impact. For example, Alfaro et al. (2004) and Borensztein et al. (1998) highlight a positive correlation between higher GDP growth rates and increased FDI inflows, suggesting that economies with robust growth prospects are more attractive to foreign investors due to the potential for higher returns. Furthermore, De Mello (1997) and Agosin and Mayer (2000) argue that FDI spurs economic development by introducing capital, transferring technology, and offering managerial expertise, which collectively boost productivity and innovation. Their research indicates that FDI enhances GDP by stimulating domestic investment and employment.

Sijabat (2023) adds that within the ASEAN region, a bidirectional causal relationship exists between FDI and GDP, particularly in the short term, highlighting the reciprocal nature of this interaction. On the contrary, a nation's GDP can also shape FDI inflows, with economic stability and growth prospects either attracting or deterring foreign investment. While the positive impacts of FDI on economic growth are well-documented, there is also evidence that FDI may have adverse effects under certain circumstances. For instance, Nguyen (2022) suggests that excessive and poorly regulated FDI inflows can potentially hinder economic growth in the host country. Similarly, research by Görg and Greenaway (2004), Sumner (2005), and Gui-Diby (2014) sheds light on the varying effects of FDI on development. Notably, Gui-Diby (2014) found a negative impact of FDI on economic growth in 50 African nations between 1980 and 1994. However, this trend reversed during the 1995-2009 period, where FDI began to positively contribute to economic growth. These findings emphasize the nuanced and complex nature of the GDP-FDI relationship, illustrating that FDI's effects on growth are context-dependent and multifaceted.

The intricate nature of economic interactions has driven increasing interest in nonlinear models, which are better suited to capturing the nuanced dynamics of these relationships. This study examines Malaysia, a rapidly developing nation in Southeast Asia, and investigates the causal relationship between its GDP and FDI through cubic regression analysis, utilizing Scilab programming for implementation.

Cubic regression, in contrast, is employed to model relationships where the connection between variables is nonlinear. Unlike linear regression, where the model parameters are linear with respect to the independent variables, cubic regression involves nonlinear relationships, making it more suitable for capturing complex dynamics. In biology, for example, nonlinear regression is used to model growth curves and enzyme kinetics (Ratkowsky, 1983). In finance, it helps capture the intricate behavior of asset prices and interest rates (Campbell et al., 1997). By incorporating nonlinear terms, such as polynomial terms, cubic regression enhances the capacity of linear models to capture complex relationships without fully adopting the complexity of a nonlinear model (Montgomery et al., 2021). Nevertheless, nonlinear regression requires careful model selection and validation to mitigate risks like overfitting and convergence issues (Seber & Wild, 2003).

In Malaysia, previous research has identified a significant relationship between FDI and economic growth (Ang, 2008; Lean & Tan, 2011). However, these studies primarily relied on linear models, potentially overlooking the bidirectional causality between GDP and FDI. This study aims to address this gap by applying nonlinear regression techniques to the Malaysian dataset, offering a more nuanced understanding of the GDP-FDI relationship.

Previous studies have extensively explored the relationship between FDI and GDP. While linear models have been commonly used, they may fail to capture complex interactions. Quadratic models offer some improvement, but they are limited in identifying more sophisticated patterns in the data. Cubic regression, with its ability to model curves with up to two turning points, provides a richer framework for understanding the nonlinearity in economic data.

Several studies have demonstrated the limitations of simpler models in capturing the dynamics of economic growth. This research builds on that foundation by employing cubic regression, which has been less commonly applied in economic studies but holds significant potential for revealing deeper insights.

2.0 Methodology

2.1. Data Collection

The data for this study were obtained from reputable Department of Statistics of Malaysia (DOSM). The dataset includes annual GDP and FDI figures over a period of twelve years from 2009-2020 given in Table 1. The data were cleaned and pre-processed to remove any inconsistencies and outliers that could distort the analysis.

Table 1: Dataset

FDI	0.512	2.918	3.733	2.854	3.818	3.56	3.938	4.703	4.042	3.074	3.2364	1.464
GDP	6.299	8.214	8.649	9.123	9.551	10.124	11.77	12.293	13.008	13.635	14.243	13.44

2.2. Cubic Regression Model

Cubic regression models offer a powerful approach to examining the relationship between GDP and FDI. Unlike linear models that assume a fixed connection between variables, cubic models provide the flexibility to capture dynamic relationships that evolve over time or vary across different levels of GDP and FDI. This adaptability is crucial in economic analysis, where the interactions between key indicators are often complex and nonlinear.

We utilize cubic regression models to analyze the bidirectional influence between FDI and GDP. Specifically, we develop Scilab code to construct these cubic regression models. The quadratic least squares formulation for the dataset can be expressed as follows, and a similar approach is applicable to both GDP and FDI. To construct a cubic regression model with GDP as the dependent variable and FDI as the independent variable, the corresponding set of equations for the GDP and FDI data (for a dataset of four observations) is presented in Eq. (1).

$$\left.\begin{aligned} B_0 + B_1FDI_1 + B_2{FDI_1}^2 + B_3{FDI_1}^3 &= GDP_1 \\ B_0 + B_1FDI_2 + B_2{FDI_2}^2 + B_3{FDI_2}^3 &= GDP_2 \\ B_0 + B_1FDI_3 + B_2{FDI_3}^2 + B_3{FDI_3}^3 &= GDP_3 \\ B_0 + B_1FDI_4 + B_2{FDI_4}^2 + B_3{FDI_4}^3 &= GDP_4 \end{aligned}\right\} \text{ Eq. (1).}$$

Rewriting Eq. (1) in matrix form gives

$$\begin{bmatrix} 1 & FDI_1 & {FDI_1}^2 & {FDI_1}^3 \\ 1 & FDI_2 & {FDI_2}^2 & {FDI_2}^3 \\ 1 & FDI_3 & {FDI_3}^2 & {FDI_3}^3 \\ 1 & FDI_4 & {FDI_4}^2 & {FDI_4}^3 \end{bmatrix} \begin{bmatrix} B_0 \\ B_1 \\ B_2 \\ B_3 \end{bmatrix} = \begin{bmatrix} GDP_1 \\ GDP_2 \\ GDP_3 \\ GDP_4 \end{bmatrix} \text{ Eq. (2)}$$

We use Eq. (2) to find the value of vector B, we have to derived as follows.

$$AB = y$$

$$A^T AB = A^T y$$

$$(A^T A)^{-1} A^T AB = (A^T A)^{-1} A^T y$$

$$B = (A^T A)^{-1} A^T y \text{ Eq. (3)}$$

Where this time,

$$A = \begin{bmatrix} 1 & FDI_1 & {FDI_1}^2 & {FDI_1}^3 \\ 1 & FDI_2 & {FDI_2}^2 & {FDI_2}^3 \\ 1 & FDI_3 & {FDI_3}^2 & {FDI_3}^3 \\ 1 & FDI_4 & {FDI_4}^2 & {FDI_4}^3 \end{bmatrix}, B = \begin{bmatrix} B_0 \\ B_1 \\ B_2 \\ B_3 \end{bmatrix}, y = \begin{bmatrix} GDP_1 \\ GDP_2 \\ GDP_3 \\ GDP_4 \end{bmatrix}$$

where B_0, B_1, B_2, and B_3 are the coefficients of the model. The cubic term $B_3 \times {FDI_i}^3$, for $i = 1,2,3,4$ allows the model to capture non-linear relationships between GDP and FDI that may not be apparent with linear or quadratic models.

To construct a cubic regression model with FDI as the dependent variable and GDP as the independent variable, the corresponding set of equations for the GDP and FDI data (for a dataset of four observations) is presented in Eq. (4).

$$\left.\begin{aligned} B_0 + B_1GDP_1 + B_2{GDP_1}^2 + B_3{GDP_1}^3 &= FDI_1 \\ B_0 + B_1GDP_2 + B_2{GDP_2}^2 + B_3{GDP_2}^3 &= FDI_2 \\ B_0 + B_1GDP_3 + B_2{GDP_3}^2 + B_3{GDP_3}^3 &= FDI_3 \\ B_0 + B_1GDP_4 + B_2{GDP_4}^2 + B_3{GDP_4}^3 &= FDI_4 \end{aligned}\right\} \text{ Eq. (4).}$$

Rewriting Eq. (4) in matrix form gives

$$\begin{bmatrix} 1 & GDP_1 & {GDP_1}^2 & {GDP_1}^3 \\ 1 & GDP_2 & {GDP_2}^2 & {GDP_2}^3 \\ 1 & GDP_3 & {GDP_3}^2 & {GDP_3}^3 \\ 1 & GDP_4 & {GDP_4}^2 & {GDP_4}^3 \end{bmatrix} \begin{bmatrix} B_0 \\ B_1 \\ B_2 \\ B_3 \end{bmatrix} = \begin{bmatrix} FDI_1 \\ FDI_2 \\ FDI_3 \\ FDI_4 \end{bmatrix} \quad \text{Eq. (5)}$$

We use Eq. (5) to find the value of vector B, we have to derived as follows.

$$AB = y$$

$$A^T AB = A^T y$$

$$(A^T A)^{-1} A^T AB = (A^T A)^{-1} A^T y$$

$$B = (A^T A)^{-1} A^T y \quad \text{Eq. (6)}$$

Where this time,

$$A = \begin{bmatrix} 1 & GDP_1 & {GDP_1}^2 & {GDP_1}^3 \\ 1 & GDP_2 & {GDP_2}^2 & {GDP_2}^3 \\ 1 & GDP_3 & {GDP_3}^2 & {GDP_3}^3 \\ 1 & GDP_4 & {GDP_4}^2 & {GDP_4}^3 \end{bmatrix}, B = \begin{bmatrix} B_0 \\ B_1 \\ B_2 \\ B_3 \end{bmatrix}, y = \begin{bmatrix} FDI_1 \\ FDI_2 \\ FDI_3 \\ FDI_4 \end{bmatrix}$$

where B_0, B_1, B_2, and B_3 are the coefficients of the model. The cubic term $B_3 \times GDP_i^3$, for $i = 1,2,3,4$ allows the model to capture non-linear relationships between GDP and FDI that may not be apparent with linear or quadratic models.

3. Implementation in Scilab

Scilab was chosen for its powerful numerical capabilities and ease of use. The cubic regression model was implemented using Scilab programming. The algorithm includes:

1. Setting observed data.
2. Calculating coefficients using Eq. (3) or Eq. (6)
3. Constructing cubic regression model
4. Predicting GDP/FDI
5. Calculating RMSE and MAPE
6. Visualising data and predicted values

4. Results and analysis

In this section, the results derived from the analysis are presented and critically examined. The data, which has been meticulously processed, serves as the foundation for interpreting the relationship between key variables. This analysis not only elucidates the patterns and trends observed but also contextualizes the findings within the broader scope of existing literature. By employing robust statistical methods, the results are scrutinized to ensure their validity and reliability, offering insights that contribute to the overall understanding of the subject matter.

From the scilab coding, we gather GDP cubic regression model as in Eq. (7)

$$GDP = 0.4494166 + 15.105819FDI - 5.9146322FDI^2 + 0.6955542FDI^3 \quad (7)$$

Eq. (7) represents a cubic regression model that quantifies the relationship between GDP (Gross Domestic Product) and FDI (Foreign Direct Investment). This model suggests that the impact of FDI on GDP is not linear, as indicated by the squared and cubic terms. Initially, as FDI increases, GDP also increases significantly (as shown by the positive coefficient of the linear FDI term). However, the negative coefficient of the squared term implies a diminishing return on GDP as FDI continues to rise. The positive cubic term further suggests that at higher levels of FDI, there might be an eventual recovery or increase in GDP, capturing potential inflection points in the relationship. This model, therefore, accounts for the complex and potentially non-linear dynamics between FDI and GDP.

The turning points for the function occur at approximately FDI=1.94 and FDI=3.73. These points indicate where the rate of change in GDP with respect to FDI shifts, which helps in analyzing both the positive returns and diminishing returns.

1. **Positive Returns (FDI < 1.94):** At lower levels of FDI (below 1.94), the relationship between FDI and GDP is characterized by positive returns. As FDI increases, GDP also rises significantly. This phase reflects the early benefits of capital inflows, technological transfer, and job creation, where the host country's economy begins to expand as a result of foreign investments.
2. **Diminishing Returns (1.94 < FDI < 3.73):** Between the first and second turning points (from 1.94 to 3.73), the returns from additional FDI begin to diminish. The negative coefficient of the squared term ($-5.9146322FDI^2$) indicates that while GDP still grows, the rate of growth slows down as the economy absorbs more FDI. This phase captures the complexity of diminishing returns, where the incremental benefits of further investment start to decrease.
3. **Potential Recovery (FDI > 3.73):** After the second turning point (beyond 3.73), the cubic term ($0.6955542FDI^3$) suggests a possible recovery, where further increases in FDI might again contribute positively to GDP growth, albeit at a different pace. This could represent scenarios where large-scale investments lead to more significant structural changes in the economy, fostering renewed growth.

This analysis underscores the importance of understanding the non-linear relationship between FDI and GDP to optimize foreign investment policies.

Table 2: Predicted GDP using Linear, Quadratic and Cubic Regression Models

Linear Regression predicted GDP	Quadratic Regression predicted GDP	Cubic Regression predicted GDP
8.839355	8.119483	6.7264665
10.68153	11.09346	11.448451
11.30554	11.35969	10.600361

10.63253	11.05667	11.554238
11.37062	11.36585	10.616495
11.17308	11.33453	10.648475
11.4625	11.36761	10.690357
12.04823	11.18768	13.023907
11.54213	11.36256	10.807753
10.80097	11.17345	11.198772
10.92532	11.24211	10.964922
9.568185	9.686898	12.069802

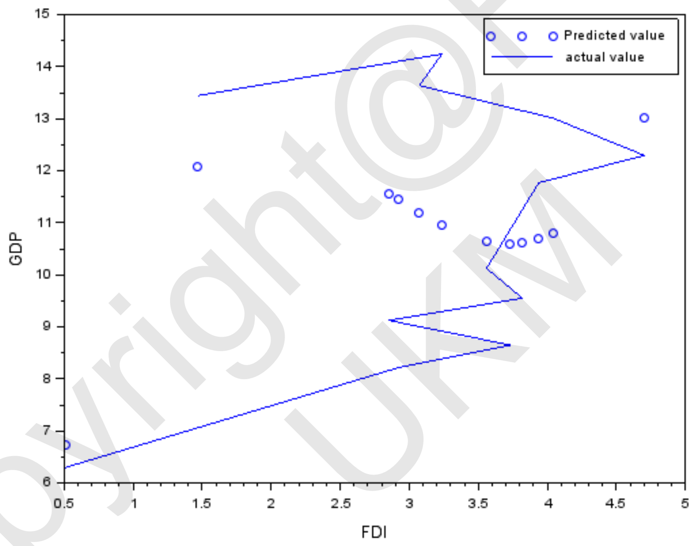

Figure 1: Plot of predicted GDP vs Observed GDP

From the scilab coding, we gather FDI cubic regression model

$$FDI = -17.747351 + 4.3888541GDP - 0.2581264GDP^2 + 0.0035455GDP^3 \quad (8)$$

Eq. (8) models the relationship between Foreign Direct Investment (FDI) and Gross Domestic Product (GDP) using a cubic regression approach. This equation implies that FDI is influenced by GDP in a non-linear manner. The positive linear term suggests that as GDP increases, FDI also increases, reflecting the general expectation that stronger economic performance attracts more foreign investment. However, the negative squared term indicates diminishing returns at certain levels of GDP, where further GDP growth might not attract as much additional FDI. The positive cubic term suggests that at higher GDP levels, there could be a recovery in FDI inflows.

The turning points of this model are found at approximately GDP=10.99 and GDP=37.55.

1. **Positive Returns (GDP < 10.99):** For GDP values below 10.99, the model indicates a positive relationship between GDP and FDI. During this phase, as GDP rises, FDI also increases. This reflects the initial attraction of foreign investment due to improved economic conditions.
2. **Diminishing Returns (10.99 < GDP < 37.55):** Between the first and second turning points, the relationship between GDP and FDI weakens. This indicates that while GDP continues to grow, the rate at which FDI increases slows down, representing diminishing returns. At this stage, the economy may be facing challenges in absorbing further investment efficiently, or the perceived opportunities for foreign investors may be levelling off.
3. **Potential Recovery (GDP > 37.55):** After GDP surpasses 37.55, the cubic term suggests a potential recovery in FDI inflows. This could indicate that at very high levels of GDP, foreign investors regain confidence or find new opportunities, leading to a renewed increase in FDI. However, since the GDP in the observed dataset only reach 13.44, thus this recovery state did not occur in the plot.

This analysis emphasizes the complexity of the GDP-FDI relationship, highlighting the importance of considering non-linear models to capture the full range of dynamics between these two key economic indicators.

Table 3: Predicted FDI using Linear, Quadratic and Cubic Regression Models

Linear Regression predicted FDI	Quadratic Regression predicted FDI	Cubic Regression predicted FDI
2.431778	0.54238	0.5423796
2.734997	2.851874	2.8518743
2.803875	3.196564	3.1965642
2.878928	3.500637	3.5006366
2.946697	3.712948	3.7129475
3.037425	3.907696	3.9076958
3.297893	3.931753	3.9317534
3.380862	3.7838	3.7838001
3.494075	3.469681	3.4696809
3.593828	3.091165	3.0911653
3.689623	2.643125	2.6431245
3.562319	3.220678	3.2206778

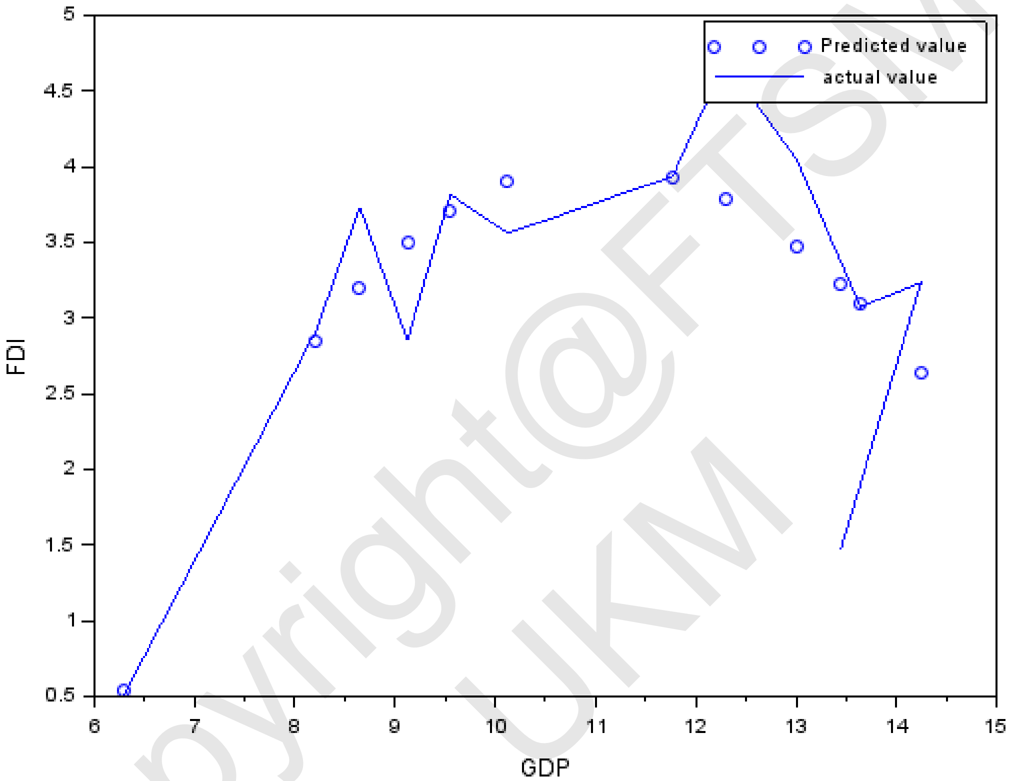

Figure 2: Plot of predicted FDI vs Observed FDI

In this paper, we analyse all model's performance using

a. goodness-of-fit metrics, such as the R-squared value and the significance of the gradient coefficients for observed vs predicted model.
b. Root mean square error (RMSE)
c. Mean absolute percentage error (MAPE)
d. Comparison with linear regression and quadratic regression

Table 4: Model parameters/metrics comparison

Parameters/metrics	Linear Model		Quadratic Model		Cubic Model	
	GDP	FDI	GDP	FDI	GDP	FDI
Gradient (obs vs predicted)	1.000024	1	0.9999	1.0000	0.9999	1
Intersection (obs vs predicted)	-0.00051	-1.3E-06	0.000699	-2.4E-07	0.000198	-6.1E-09
r^2 (obs vs predicted)	0.121233	0.121233	0.148347	0.62995	0.3423	0.62995
RMSE	2.284571	1.038917	2.248788	0.692803	1.314369	0.674177
MAPE	19.65071	56.38942	19.96362	20.44062	14.39638	3.887021

Pineiro et al. (2008) suggest to use observed vs predicted linear regression model to evaluate the accuracy of model. The gradient coefficient indicates relationship between observed values and predicted values. The gradient coefficient for all observed vs predicted models are 1 or almost 1 suggests a nearly one-to-one relationship between observed and predicted values. This means that all models accurately predict GDP or FDI data. The R^2 value indicates how well the predicted values explains the variability in observed values. The GDP Cubic Model has the highest R^2 value (0.3423), suggesting that predicted GDP values explains the variability in observed GDP better than the GDP Linear and GDP Quadratic models. While FDI Cubic and Quadratic models have the highest R^2 value (0.62995), suggesting that predicted FDI values explains the variability in observed FDI better than the FDI Linear model. However, it is important to note that a low R^2 value does not inherently imply that the model lacks utility. Instead, it may suggest that the relationship between the variables is intricate or that there are additional factors influencing the outcome that have not been accounted for in the model.

RMSE measures the average magnitude of the errors between predicted and observed values. The Cubic Models has the lowest RMSE (1.314369 for GDP Cubic model and 0.674177 for FDI Cubic model), indicating both GDP and FDI Cubic models has the smallest average error and is the most accurate among the six models.

MAPE measures the accuracy of the model as a relative percentage. The Cubic Model has the lowest MAPE (14.39638 for GDP cubic model and 3.887021 for FDI Cubic model), indicating both GDP and FDI Cubic models have the highest accuracy.

Based on the provided metrics, the Cubic Model outperforms the Linear and Quadratic models in terms of explaining variability (R^2), accuracy (RMSE), and prediction accuracy (MAPE). This suggests that the relationship between GDP and FDI is best captured by a cubic relationship, which aligns with the initial analysis of the equation gathered.

5. Discussions

The cubic regression model provided a better fit to the data compared to linear and quadratic models, as indicated by higher R-squared values and significant coefficients for the cubic terms. The model successfully captured the nonlinear dynamics between GDP and FDI, revealing that FDI's impact on GDP varies at different levels of economic development.

For instance, the analysis showed that at low levels of FDI, the impact on GDP is positive but diminishes as FDI increases, reaching a turning point where additional FDI may even negatively affect GDP, possibly due to diminishing returns or other economic constraints.

The results underscore the importance of considering nonlinear models when studying the relationship between GDP and FDI. While linear models can provide a general overview, they may miss crucial details that cubic regression can uncover. The findings suggest that policymakers should be cautious about interpreting FDI's impact on economic growth in a simplistic manner. Instead, they should consider the stage of economic development and other contextual factors.

Scilab proved to be a robust tool for this analysis, offering an accessible platform for conducting complex economic modelling. Its open-source nature also makes it a viable option for researchers in developing countries or institutions with limited resources.

6. Conclusions

This study highlights the value of cubic regression in modelling the GDP-FDI relationship. By capturing nonlinearities that simpler models may overlook, cubic regression provides a more nuanced understanding of how FDI influences GDP. The use of Scilab in this research demonstrates the feasibility of applying advanced econometric techniques in an open-source environment, making such analyses accessible to a broader audience.

Future research could extend this approach by incorporating additional variables, such as trade openness or inflation, to further refine the model. Additionally, applying cubic regression to different regions or sectors could offer new insights into the diverse effects of FDI on economic growth.

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