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RESEARCH

Modelling and Analysis of the Impact of Corruption on Economic Growth and Unemployment

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Abstract

This study explores the complex interplay between economic growth, corruption, and unemployment in the context of sub-Saharan Africa. Employing a new, dynamic mathematical model, we move beyond static correlations to analyze how these factors influence each other over time. Our findings suggest corruption acts like a parasite, siphoning resources away from productive activities and hindering economic progress. This translates to fewer jobs and higher unemployment rates. Conversely, a focus on efficient resource allocation and sustainable development fosters economic growth. Additionally, a robust entrepreneurial sector creates new employment opportunities, further reducing unemployment. The model underscores the need for a multifaceted approach. While effective anti-corruption measures are crucial, so are policies that promote private ownership and job creation within existing businesses. Imagine a three-pronged strategy: combating corruption, stimulating existing job markets, and fostering entrepreneurship. Furthermore, strengthening institutions to tackle corruption allows for swifter responses, minimizing its negative impact on economic growth. By simultaneously addressing corruption and fostering job creation through this multifaceted approach, we can create a balanced and stable economic environment conducive to sustainable development and a brighter future for sub-Saharan Africa.

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1 Introduction

Economic growth, the lifeblood of a nation's prosperity as measured by gross domestic product (GDP) [1], reflects a growing economy producing more goods and services [2]. While a healthy growth rate translates to rising living standards, job creation, and poverty reduction [3], achieving this balance can be a complex challenge, especially for developing regions like sub-Saharan Africa [4, 5]. After a period of strong growth and surprising resilience during the 2008 crisis [6], sub-Saharan Africa now faces a more complex reality. The World Bank estimates growth will slow to 2.5% in 2023, down from 3.6% in 2022 [7].

In sub-Saharan Africa, corruption acts as a stranglehold on economic growth, suffocating its potential. Extensive research underscores this detrimental impact across various societal aspects, including political stability, skill development, and entrepreneurial activity [8–10]. By diverting resources from vital infrastructure, education, and healthcare through bribes and embezzlement, it weakens the foundation for progress [11, 12]. This fosters a hostile environment for businesses, discouraging investment due to unfair competition and bureaucratic hurdles fuelled by corruption [13, 14]. Public trust erodes, leading to decreased tax compliance and a weakened economic system [15]. Businesses become inefficient, wasting resources navigating a web of bribes and favours [16]. Talented individuals are drawn towards rent-seeking activities, hindering innovation [17, 18]. This vicious cycle of stunted growth creates further opportunities for corruption, as a weakened economy becomes more susceptible [19, 20]. Breaking free requires strong anti-corruption measures, transparency, and accountability [21].

The relationship between corruption and economic growth is a complex one, with differing viewpoints explored in various research articles. Some studies argue that corruption hinders economic progress by diverting resources away from productive endeavours and creating uncertainty for businesses [9, 18, 20]. Additionally, corruption can exacerbate income inequality, further stalling economic growth [22]. Conversely, other research suggests a moderate level of corruption might even benefit economic growth in certain contexts. This argument centres on the idea that corruption can act as a substitute for weak institutions, expediting processes like obtaining permits [23]. The ultimate impact of corruption appears to be contingent on a nation's institutional environment. In countries with strong institutions, corruption is more likely to be detrimental to growth. Conversely, in countries with weak institutions, corruption may have a less negative or even a positive impact on growth [17].

Corruption's grip extends beyond hindering economic growth, impacting unemployment as well. Businesses forced to divert resources towards bribes have less for innovation and investment, stifling formal job creation [24, 25]. Additionally, corrupt environments discourage foreign investment, further limiting job opportunities [26]. Unethical hiring practices favouring connections over qualifications exacerbate the issue, leading to inefficiencies and discouraging skilled workers from entering the market [27]. However, corruption might incentivize informal jobs in some contexts, though these often lack security and benefits [28]. The impact on unemployment depends on factors like the type and level of corruption, institutional strength, and the economic structure [29].

Economic analysis hinges on mathematical models [30]. Differential equations are a cornerstone of economic analysis for continuously evolving phenomena. They empower economists to explore diverse areas. The Solow growth model investigates how population and technological advancements affect long-term output per person [31]. Building on this, the Ramsey-Cass-Koopmans model uses differential equations to optimize consumption choices for future growth [32–34]. Their applications extend beyond growth: the Lotka-Volterra model, adapted from ecology, sheds light on firm competition for market share [35]. Differential equations are also instrumental in building inflation models that consider factors like money supply to predict price changes [36, 37]. Even in finance, the Black-Scholes model, which revolutionized stock option pricing, relies on a differential equation [38]. While these models are powerful tools for analyzing economic interactions and forecasting future trends, it's important to remember they are simplified representations of reality. Empirical studies have illuminated the complex relationships between corruption, unemployment, and economic growth [39, 40], but a critical gap remains in exploring their dynamic interplay through rigorous mathematical modelling. Existing approaches, such as the Okun law, offer valuable insights into the reciprocal relationship between unemployment reduction and GDP growth [41–44]. However, incorporating corruption adds a layer of complexity, necessitating more sophisticated modelling approaches to capture the intricate and interconnected nature of these factors.

This study tackles a critical gap in understanding economic development in sub-Saharan Africa. We propose a new mathematical model that captures the complex interplay between economic activity, corruption, and unemployment, a pervasive challenge in the region. Our model advances beyond existing approaches by incorporating both direct and indirect effects, providing a holistic understanding of the underlying mechanisms. Grounded in sound economic theory, our analysis goes beyond explaining current observations. We aim to inform policy debates to achieve a future marked by sustainable economic growth, reduced unemployment, and improved societal well-being. Ultimately, our research aspires to contribute to data-driven policymaking that fosters sub-Saharan Africa's economic growth while tackling unemployment. By untangling the intricate relationship between corruption, economic prosperity, and unemployment, we hope to equip policymakers with actionable insights to confront pressing challenges and pave the way for a more just and sustainable future for all citizens across sub-Saharan Africa.

The subsequent sections delve deeper into our model, outlining its assumptions and theoretical foundations, followed by validation through numerical simulations. We conclude by discussing the broader implications and avenues for future research.

2 Model Formulation

This section presents a novel non-linear system of ordinary differential equations (ODEs) that captures the dynamic interplay between economic growth $(G(t))$, corruption density $(C(t))$, and unemployment density $(U(t))$ over time (t). All actors, including economic agents, corrupt officials, and the unemployed, are assumed to act rationally based on their inherent motivations and available information. The model operates within a closed system where external factors have minimal influence on the dynamics of the three variables. Continuous changes in all variables are assumed over time. Economic growth follows a logistic pattern, reaching a carrying capacity (K_1) due to resource limitations. This is represented by the following:

$$\frac{dG}{dt} = r_1 G\left(1 - \frac{G}{K_1}\right) - \frac{\beta G C}{1 + a\beta G},$$

where r_1 represents the intrinsic growth rate of the economy and K_1 denotes the economic carrying capacity. Corruption negatively impacts economic growth by siphoning resources away from productive activities. This is incorporated a term that accounts for the impact of corruption:

$$\frac{\beta G C}{1 + a\beta G},$$

where β representing the rate at which corrupted officials encounter economic resources (attack rate) and a, representing the average time spent processing corruption(handling time). Corrupted officials convert some accessed resources into personal gain based on a specific conversion rate (ϕ). Corruption naturally dissipates over time due to factors like detection and enforcement (μ). These assumptions are reflected in the following equation:

$$\frac{dC}{dt} = \phi \frac{\beta G C}{(1 + a\beta G)} - \mu C,$$

Unemployment follows a logistic pattern, reaching a maximum level (K_2) due to factors such as population growth. Job creation is influenced by economic growth and hindered by corruption. The evolution of unemployment density $(U(t))$ is given by the following:

$$\frac{dU}{dt} = r_2 U(1 - \frac{(U + \xi G)}{K_2}),$$

where r_2 represents the unemployment growth rate, and economic growth creates new job opportunities at a constant rate (ξ). Corruption negatively impacts job creation by hindering economic activity and investment. These assumptions are reflected in the following equation:

$$\frac{dU}{dt} = r_2 U(1 - \frac{(U + \xi G)}{K_2}) - \kappa U,$$

where κ represents new private business density rate $(\kappa < r_2)$.

Combining the above assumptions and equations, we obtain the complete system of differential equations:

$$\begin{aligned}
\frac{dG}{dt} &= r_1 G\left(1-\frac{G}{K_1}\right)-\frac{\beta GC}{1+a\beta G},\\
\frac{dC}{dt} &= \phi\frac{\beta GC}{1+a\beta G}-\mu C,\\
\frac{dU}{dt} &= r_2 U\left(1-\frac{U+\xi G}{K_2}\right)-\kappa U.
\end{aligned} \tag{1}$$

The model assumes non-negative initial values for all variables: $G(0) \geq 0$, $C(0) \geq 0$, $U(0) \geq 0$.

This model provides a mathematical framework to explore the complex interactions between economic growth, corruption, and unemployment. By analyzing the model's behaviour under different parameter settings and incorporating additional assumptions in future research, we can gain valuable insights into the potential long-term outcomes and policy implications for promoting sustainable economic growth, combating corruption, and reducing unemployment

2.1 Boundedness of the Model

The equations in the system (1) have smooth right-hand sides that are functions of the variables G, C, and U. Additionally, all parameters within the system are non-negative. As demonstrated in the following theorem, all solutions are guaranteed to remain within the defined region, Ω.

Theorem 1 *All solutions of the model with initial conditions in the positive orthant of the three-dimensional space (denoted by R^3_+) remain uniformly bounded within a specific region, denoted by Ω. This region is defined as follows:* $\Omega = \Big\{(G, C, U) : 0 \leq G + C + U \leq \frac{r_1\theta K_1}{\theta_0}\Big\}$, *where* $\theta_0 = \min\big\{(r_1(\theta-1),\ -\mu,\ \kappa - r_2)\big\}$.

Proof Consider the first equation of the system:

$$\frac{dG}{dt} \leq r_1 G\left(1-\frac{G}{K_1}\right).$$

Applying the upper bound principle, we have the following:

$$\lim_{t\to\infty} G \leq K_1.$$

Therefore, G is bounded above by K_1 in the long run. Define the Lyapunov function:

$$V(t) = G(t) + C(t) + U(t).$$

Taking the derivative of V(t) and utilizing the equations from the system,

$$\begin{aligned}\frac{dV}{dt} &= \left(r_1G - \frac{r_1G^2}{K_1} - (1-\phi)\frac{\beta GC}{1+a\beta G} \right.\\ &\quad \left. - \mu C + (r_2-\kappa)U - \frac{r_2U^2}{K_2} - \frac{r_2\xi UG}{K_2} \right),\\ &\le r_1G - \mu C - (\kappa - r_2)U,\\ &= \theta r_1 G - r_1(\theta-1)E - \mu C - (\kappa - r_2)U,\\ &\le \theta r_1 G - \theta_0 V(t),\\ &= \theta r_1 K_1 - \theta_0 V(t).\end{aligned}$$

Hence, $\frac{dV}{dt} \le \theta r_1 G - \theta_0 V(t)$, where $\theta_0 = \min\left\{(r_1(\theta-1),\ -\mu,\ \kappa - r_2)\right\}$ and θ is any constant value. Rearranging the inequality,

$$\frac{dV}{dt} + \theta_0 V(t) \le \theta r_1 K_1.$$

By the theorem of differential inequalities, we obtain:

$$0 \le V(t) \le V(0)e^{-\theta_0 t} + \frac{r_1\theta K_1}{\theta_0}.$$

Taking the limit as t approaches infinity,

$$0 \le V \le \frac{r_1\theta K_1}{\theta_0}.$$

Since $V(t)$ represents the sum of $G(t)$, $C(t)$, and $U(t)$, all solutions of the system are bounded within the region:

$$\Omega = \left\{(G, C, U) : 0 \le G + C + U \le \frac{r_1\theta K_1}{\theta_0}\right\}.$$

Therefore, all solutions starting in the positive orthant remain confined within this region over time. □

3 Model Equilibrium and Their Stability

3.1 Possible Equilibria in the System

This subsection explores the equilibrium points of the system described by Eq. (1). These points represent potential steady states where the rates of change for economic resources (G), corruption density (C), and unemployment density (U) become zero. Identifying and analyzing these equilibria provide valuable insights into the system's long-term behaviour under different parameter settings. The system exhibits several non-negative equilibria, meaning all state variables remain non-negative. These equilibria can be categorized as follows:

- Trivial equilibrium: $E_0 = (0, 0, 0)$. This represents the complete absence of economic resources, corruption, and unemployment.
- Axial equilibria:
  - $E_1 = (0, 0, \frac{K_2(r_2-\kappa)}{r_2})$ reflects the absence of economic resources and corruption, with unemployment reaching a specific level governed by the growth and depletion rates.
  - $E_2 = (K_{,}0, 0)$ signifies a state with maximum economic resources (carrying capacity) but no corruption and unemployment.
- Economic-specific equilibria: $E_3 = (K_1, 0, K_2\left(1 - \frac{\kappa}{r_2}\right) - \xi K_1)$ represents maximum economic resources, no corruption, and a specific unemployment level determined by job creation and resource depletion rates.
- Unemployment-free equilibrium: $E_4 = \left(\frac{\mu}{\beta(\phi - a\mu)}, \frac{\phi r_1}{1+a\beta K_1}\left(\frac{\beta K_1}{1+a\beta K_1} - \mu\right), 0\right)$ exhibits the absence of unemployment but with specific positive values for economic resources and corruption.
- Positive interior equilibrium: $E^* = (G^*, C^*, U^*)$ constitutes the most intricate case, representing a non-trivial steady state with positive values for all variables:
  - $G^* = \frac{\mu}{\beta(\phi - a\mu)}$ represents a specific level of economic resources.
  - $C^* = \frac{r_1\phi(\beta K_1(\phi - a\mu) - \mu)}{\beta^2 K_1(\phi - a\mu)^2}$ signifies a specific level of corruption density.
  - $U^* = K_2\left(1 - \frac{\kappa}{r_2}\right) - \frac{\mu\xi}{\beta(\phi - a\mu)}$ represents a specific level of unemployment density.

The presence of these equilibrium points highlights the potential for the system to settle into various long-term states depending on the initial conditions and parameter values. Analyzing their stability and the basins of attraction for each equilibrium can offer valuable insights into the possible dynamics and outcomes of the system in different scenarios.

3.2 Stability of Equilibria

This subsection will briefly explore the stability of the identified equilibrium points in the previous subsection. Stability refers to the system's behaviour when subjected to small perturbations from an equilibrium state. If the system returns to the equilibrium point after such a perturbation, it is considered stable. Conversely, if the system deviates further from the equilibrium point, it is considered unstable. To analyze stability, we employ linearization around each equilibrium point. This involves approximating the non-linear system with a corresponding linear system valid in the vicinity of the equilibrium point. We use the Jacobian matrix, which represents the partial derivatives of the system's right-hand side functions concerning each variable. Let $X = (G, C, U)$ be the state vector. The Jacobian matrix of the system (1) evaluated at point X is as follows:

$$J(X) = \begin{pmatrix} r_1\left(1 - \frac{2G}{K_1}\right) - \frac{\beta C}{(1+a\beta G)^2} & -\frac{\beta G}{1+a\beta G} & 0 \\ \frac{\phi\beta C}{(1+a\beta G)^2} & \frac{\phi\beta G}{1+a\beta G} - \mu & 0 \\ -\frac{r_2 U}{K_2} & 0 & r_2\left(1 - \frac{2U+\xi G}{K_2}\right) - \kappa \end{pmatrix}. \quad (2)$$

The stability of each equilibrium point can be determined by analyzing the eigenvalues of the corresponding Jacobian matrix.

Theorem 2 *The trivial equilibrium point* $E_0 = (0, 0, 0)$ *is always unstable.*

Proof The Jacobian matrix of the system (1) evaluated at the trivial equilibrium point $E_0 = (0, 0, 0)$ becomes the following:

$$J(E_0) = \begin{pmatrix} r_1 & 0 & 0 \\ 0 & -\mu & 0 \\ 0 & 0 & r_2 - \kappa \end{pmatrix}.$$

The eigenvalues of this matrix are $\lambda_1 = r_1$, $\lambda_2 = -\mu$, and $\lambda_3 = r_2 - \kappa$. Since r_1 and $r_2 - \kappa$ are positive by definition (intrinsic growth rate and the difference between growth and depletion rate cannot be negative), the eigenvalues λ_1 and λ_3 are always positive. According to the principle of eigenvalue analysis, an equilibrium point with at least one eigenvalue having a positive real part is unstable. Therefore, the trivial equilibrium point E_0, which has two positive eigenvalues (λ_1 and λ_3), is always unstable.

Therefore, the trivial equilibrium point (E_0) is always unstable, implying that if the system starts at this point with minimal or no resources, corruption, and unemployment, it will not remain at this state and will tend to move away from it. □

The instability of the trivial equilibrium point signifies that the complete absence of economic resources, corruption, and unemployment is not a sustainable long-term state for the system. In the absence of resources ($G = 0$), the system cannot effectively combat corruption (C) or address unemployment (U). This highlights the importance of initial conditions and the potential dynamics of the system under different scenarios.

Theorem 3 *The positive equilibrium point* $E_1 = (0, 0, \frac{K_2(r_2-\kappa)}{r_2})$ *is always unstable.*

Proof The Jacobian matrix of the system (1) evaluated at E_1 is as follows:

$$J(E_1) = \begin{pmatrix} r_1 & 0 & 0 \\ 0 & -\mu & 0 \\ \kappa - r_2 & 0 & \kappa - r_2 \end{pmatrix}.$$

The eigenvalues of this matrix are $\lambda_1 = r_1$, $\lambda_2 = -\mu$, and $\lambda_3 = \kappa - r_2$, since the eigenvalue $\lambda_1 > 0$ has a positive real part. According to the principle of eigenvalue analysis, when all eigenvalues of the Jacobian matrix at an equilibrium point have positive real parts, the equilibrium point is unstable.

Therefore, the equilibrium point E_1 is always unstable, implying that if the system starts at this state with no resources and corruption but some unemployment, it will not remain at this state and will tend to move away from it. □

The instability of the equilibrium point E_1 suggests that maintaining a specific level of unemployment ($U > 0$) in the absence of any economic resources ($G = 0$) and corruption ($C = 0$) is not a sustainable long-term state for the system. In the absence of resources, the system cannot address unemployment, even if corruption is absent. This highlights the importance of examining the system's dynamics under different initial conditions and parameter settings.

Theorem 4 *The equilibrium point* $E_2 = (K_1, 0, 0)$ *is locally asymptotically stable if* $\mu > \frac{\phi\beta K_1}{1+a\beta K_1}$ *and* $r_2 K_2 < (\kappa K_2 + r_2 \xi K_1)$.

Proof The Jacobian matrix of the system (1) evaluated at E_2 is as follows:

$$J(E_2) = \begin{pmatrix} -r_1 & -\frac{\beta K_1}{a\beta K_1+1} & 0 \\ 0 & \frac{\beta\phi K_1}{a\beta K_1+1} - \mu & 0 \\ 0 & 0 & \left(1 - \frac{\xi K_1}{K_2}\right) r_2 - \kappa \end{pmatrix}.$$

The eigenvalues of this matrix are $\lambda_1 = -r_1$, $\lambda_2 = \frac{\phi\beta K_1}{1+a\beta K_1} - \mu$, and $\lambda_3 = \frac{r_2 K_2 - (r_2 \xi K_1 + \kappa K_2)}{K_2}$. It is clear that $\lambda_1 < 0$. Now, E_1 is stable if $\lambda_2 < 0$ and $\lambda_3 < 0$; that is, $\mu > \frac{\phi\beta K_1}{1+a\beta K_1}$ and $r_2 K_2 < (\kappa K_2 + r_2 \xi K_1)$.

All eigenvalues must have negative real parts for E_2 to be locally asymptotically stable. Since λ_1 is already negative due to the negative growth rate ($-r_1$), the following conditions must hold:

1. Condition 1: $\mu > \frac{\phi\beta K_1}{1+a\beta K_1}$, ensures $\lambda_2 < 0$.
2. Condition 2: $r_2 K_2 < (\kappa K_2 + r_2 \xi K_1)$, ensures $\lambda_3 < 0$.

If both conditions are satisfied, all eigenvalues have negative real parts, making the equilibrium point E_2 locally asymptotically stable. If the system starts near E_2, any small perturbations will cause it to return to E_2 over time.

□

The concept of local asymptotic stability applied to state E_2 in this model suggests an ideal long-term economic scenario: full resource utilization ($G = K_1$) with zero corruption ($C = 0$) and zero frictional unemployment ($U = 0$). However, this economic nirvana is contingent upon specific economic parameters. The crucial factors revolve around efficacious anti-corruption measures and robust job creation. The rate of corruption eradication (μ) must surpass a critical threshold, ensuring corruption's decline outpaces any potential resurgence. Additionally, the natural rate of unemployment must be lower than the job creation spurred by economic growth (ξ) and entrepreneurial activity (κ). This underscores the importance of calibrating economic levers, such as policies that clamp down on corruption and incentivize business formation. In essence, achieving this ideal state necessitates a delicate balancing act: throttling corruption while fostering an environment that generates sufficient jobs to absorb the entire labour force.

Theorem 5 *The corruption-free equilibrium point* $E_3 = (K_1, 0, K_2\left(1 - \frac{\kappa}{r_2}\right) - \xi K_1)$ *is locally asymptotically stable if the conditions* $\mu > \frac{\phi\beta k_1}{1+a\beta k_1}$ *and* $r_2 K_2 > (\kappa K_2 + \xi K_1)$ *hold.*

Proof The Jacobian matrix of the system (1) evaluated at E_3 is as follows:

$$J(E_3) = \begin{pmatrix} -r_1 & -\frac{\beta K_1}{a\beta K_1+1} & 0 \\ 0 & \frac{\beta\phi K_1}{a\beta K_1+1} - \mu & 0 \\ \kappa + \left(\frac{\xi K_1}{K_2} - 1\right) r_2 & 0 & \kappa + \left(\frac{\xi K_1}{K_2} - 1\right) r_2 \end{pmatrix}$$

The eigenvalues of this matrix are $\lambda_1 = -r_1$, $\lambda_2 = \frac{\beta\phi K_1}{a\beta K_1+1} - \mu$ and $\lambda_3 = \frac{(\kappa K_2 + \xi K_1) - r_2 K_2}{K_2}$. All eigenvalues must have negative real parts for E_3 to be locally asymptotically stable. Clearly, λ_1 is negative translates to the following conditions:

- Condition 1: $\mu > \frac{\phi\beta k_1}{1+a\beta k_1}$, ensures $\lambda_2 < 0$.
- Condition 2: $r_2 K_2 > (\kappa K_2 + \xi K_1)$, ensures $\lambda_3 < 0$

If both conditions are satisfied, the equilibrium point E_3 is locally asymptotically stable. If the system starts near E_3, any small perturbations will cause it to return to E_3 over time. □

The economic model suggests a fascinating, yet challenging, long-term scenario (E_3). Here, the economy could operate at full capacity (maximum resource utilization) with zero corruption, but a constant level of unemployment would persist due to factors like automation or a skills gap. This highlights a potential trade-off: achieving full employment might not be possible even with a perfect economic environment. The key takeaway is that under specific conditions, eliminating corruption and maximizing output might be achievable despite this unemployment. However, to ensure a more balanced and sustainable future, policymakers need to focus on understanding the root causes of unemployment, such as automation and skills gaps. By addressing these factors through targeted policies like job retraining programs and technological advancements that create new jobs, we can strive for a future with both high economic output and full employment.

Theorem 6 *Unemployment-free equilibrium point* $E_4 = \left(\frac{\mu}{\beta(\phi - a\mu)}, \frac{\phi r_1}{1+a\beta K_1}\left(\frac{\beta K_1}{1+a\beta K_1} - \mu\right), 0\right)$ *is locally asymptotically stable if* $r_2 < \left(\frac{r_2\xi\mu}{\beta K_2(\phi - a\mu)} + \kappa\right)$ *and* $\left(\mu + \frac{\phi}{a(1+\beta a K_1)}\right) > \frac{\phi\beta K_1}{1+\beta a K_1}$.

Proof The Jacobian matrix evaluated at E_4 is given as follows:

$$J(E_4) = \begin{pmatrix} \frac{\mu r_1(a\beta K_1(a\mu-\phi)+a\mu+\phi)}{\beta K_1\phi(a\mu-\phi)} & -\frac{\mu}{\phi} & 0 \\ -\frac{r_1(\beta K_1(a\mu-\phi)+\mu)}{\beta K_1} & 0 & 0 \\ 0 & 0 & r_2\left(\frac{\mu\xi}{a\beta K_2\mu-\beta K_2\phi}+1\right)-\kappa \end{pmatrix}.$$

Clearly, we obtained $\lambda_1 = r_2 - \left(\frac{r_2\xi\mu}{\beta K_2(\phi-a\mu)}+\kappa\right)$. The result show that the eigenvalue λ_1 is negative where $r_2 < \left(\frac{r_2\xi\mu}{\beta K_2(\phi-a\mu)}+\kappa\right)$. The polynomial determines the remaining two eigenvalues

$$\lambda^2 + c_1\lambda + c_0 = 0,$$

where $c_1 = \frac{\mu r_1(a\mu+\phi-a\beta K_1(\phi-a\mu))}{\beta K_1\phi(\phi-a\mu)}$ and $c_0 = \frac{\mu r_1(\beta K_1(\phi-a\mu)-\mu)}{\beta K_1\phi}$. Clearly, $c_0 > 0$ and c_1 is positive where $\left(\mu+\frac{\phi}{a(1+\beta a K_1)}\right) > \frac{\phi\beta K_1}{1+\beta a K_1}$.

The Routh-Hurwitz criterion gives a set of necessary and sufficient conditions for all the roots of the polynomial (3) to have a negative real part whenever $c_1 = \frac{\mu r_1(a\mu+\phi-a\beta K_1(\phi-a\mu))}{\beta K_1\phi(\phi-a\mu)} > 0$ and $c_0 = \frac{\mu r_1(\beta K_1(\phi-a\mu)-\mu)}{\beta K_1\phi} > 0$. Hence, the unemployment-free equilibrium E_4 is locally asymptotically stable. □

This economic model examines the conditions required to attain a stable state with zero unemployment. The key insight is that two economic factors must work in tandem to achieve this goal. First, the rate of job creation driven by economic growth must exceed the natural growth rate of the unemployed population. This necessitates economic policies that stimulate business creation, innovation, and investment. Second, the negative impacts of corruption on resource availability must be controlled. While it may not be possible to eliminate corruption, its adverse effects can be mitigated through policies that promote transparency, accountability, and good governance. This creates a scenario where economic growth, despite some level of corruption, can still generate enough jobs to absorb the growing workforce and maintain zero unemployment. The insights from this model provide policymakers with valuable guidance in developing strategies to foster economic growth, job creation, and a healthy business environment with controlled corruption. Policymakers can target these factors by promoting economic growth through investment and education initiatives while combating corruption through measures that enhance transparency and good governance practices.

Theorem 7 *The positive interior equilibrium E^* is locally asymptotically stable if $r_2 > \left(\frac{r_2\xi\mu}{\beta K_2(\phi-a\mu)}+\kappa\right)$ and $\left(\mu+\frac{\phi}{a(1+\beta a K_1)}\right) > \frac{\phi\beta K_1}{1+\beta a K_1}$.*

Proof We evaluate the Jacobian matrix (2) at E^*, and we get the eigenvalue $\lambda_1 = \left(\frac{r_2\xi\mu}{\beta K_2(\phi-a\mu)}+\kappa\right) - r_2$. The result implies that the eigenvalue λ_1 is negative whenever $r_2 > \left(\frac{r_2\xi\mu}{\beta K_2(\phi-a\mu)}+\kappa\right)$. The sub-characteristics polynomial determines the sign of the remaining two eigenvalues

$$\lambda^2 + a_1\lambda + a_0, \tag{3}$$

where $a_1 = \frac{\mu r_1(a\mu+\phi-a\beta K_1(\phi-a\mu))}{\beta K_1\phi(\phi-a\mu)}$ and $a_0 = \frac{\mu r_1(\beta K_1(\phi-a\mu)-\mu)}{\beta K_1\phi}$. Clearly, $a_0 > 0$ and a_1 are positive where $\left(\mu + \frac{\phi}{a(1+\beta a K_1)}\right) > \frac{\phi\beta K_1}{1+\beta a K_1}$.

The Routh-Hurwitz criterion gives a set of necessary and sufficient conditions for all the roots of the polynomial (3) to have negative real part if $a_1 = \frac{\mu r_1(a\mu+\phi-a\beta K_1(\phi-a\mu))}{\beta K_1\phi(\phi-a\mu)} > 0$ and $a_0 = \frac{\mu r_1(\beta K_1(\phi-a\mu)-\mu)}{\beta K_1\phi} > 0$. Hence, the positive interior equilibrium E^* is locally asymptotically stable. □

This economic model delves into the possibility of a stable economic state with positive levels of economic resources, corruption, and unemployment. Theorem 7 identifies the key factors influencing this stable state (E^*). The first factor is maintaining a balance between job creation and unemployment growth. Economic policies that stimulate business creation, innovation, and investment are crucial to ensure job growth outpaces the increase in the workforce. Secondly, the theorem acknowledges that some level of corruption might exist in a stable state. However, it emphasizes the importance of the corruption depletion rate, which reflects the effectiveness of anti-corruption efforts. This depletion rate, influenced by transparency and enforcement measures, needs to be sufficiently high for long-term stability. In essence, achieving this stable state requires a two-pronged approach: fostering economic growth and job creation through investment and education initiatives, while simultaneously implementing effective anti-corruption measures that address the root causes of corruption and promote transparency. While a state with some level of corruption might not be ideal, understanding the factors that influence its stability can guide policymakers in designing realistic economic development strategies that consider both growth and controlling corruption.

4 Numerical Result and Discussion

To bridge the theory-practice gap and explore economic implications, this section uses numerical simulations. We will build a computer model mimicking the system (1) to simulate how economic activity, corruption prevalence, and unemployment evolve, particularly around the identified equilibrium. This will visually confirm the theoretical predictions about their stability. Additionally, a sensitivity analysis will involve varying economic factors (model parameters) to see how they influence the system's dynamics. By simulating the effects of changes like increased investment or stronger anti-corruption measures, we can gain valuable insights into how real-world events or policies might impact the stability and economic indicators. This combined approach bridges theory and practice, validating theoretical predictions and informing policymakers on designing strategies for economic growth, job creation, and controlled corruption. We employ MATLAB software and its ode45 function, which implements the Runge–Kutta algorithm, to perform the simulations.

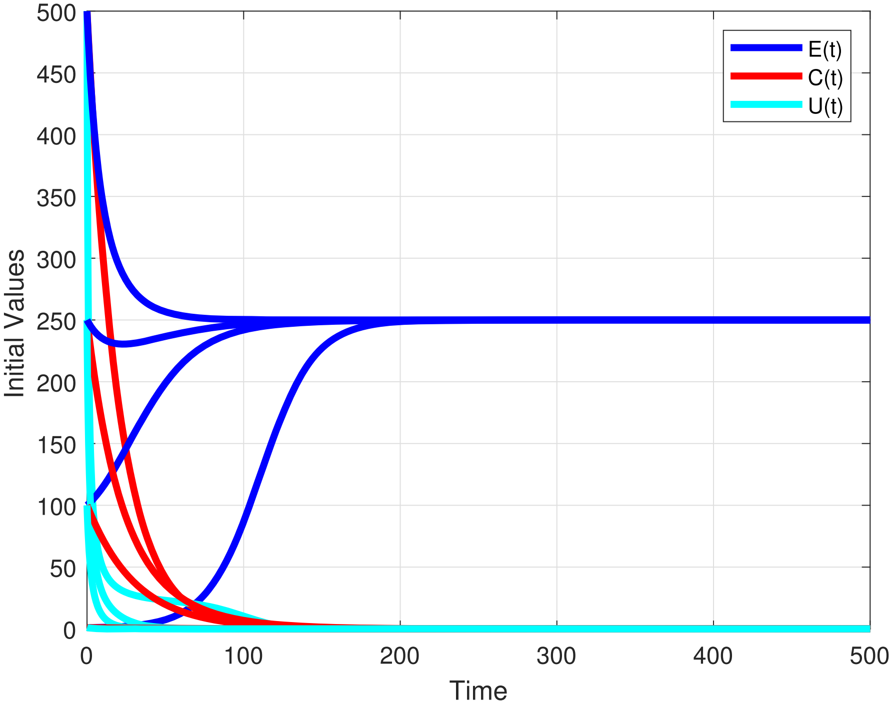

Fig. 1 The stability of E_2 of system (1) by varying the initial conditions

4.1 Dynamic Stability of Equilibria

To prove the locally asymptotic stability of the equilibrium $E_2 = (K_1,\ 0,\ 0)$ in Theorem 4, we set the parameters $r_1 = 0.059, r_2 = 0.0618, \xi = 1/3, \phi = 0.77, K_1 = 250,$ $K_2 = 25, \mu = 0.05, \kappa = 0.005, a = 1.25, \beta = 0.0001$. A straightforward calculation exhibits that $\mu = 0.05 > \frac{\phi\beta K_1}{1+a\beta K_1} = 0.019$ and $r_2 K_2 = 1.5450 < (\kappa K_2 + r_2 \xi K_1)$ $= 5.2750$, which complete the stability conditions of Theorem 4. Computing it further, we get $E_2 = (250, 0, 0)$ where the eigenvalues $J(E_2)$ are $\lambda_1 = -0.1492$, $\lambda_2 = -0.059, \lambda_3 = -0.0313333$. From the result, all eigenvalues are negative, which verifies that the equilibrium E_2 of the system (1) is locally asymptotically stable.

Figure 1 demonstrates that the positive equilibrium $E_2 = (K_1,\ 0,\ 0) = (250, 0, 0)$ of the system (1) is locally asymptotically stable when $\mu = 0.05 > \frac{\phi\beta K_1}{1+a\beta K_1} = 0.0187$ and $r_2 K_2 = 1.545 < (\kappa K_2 + r_2 \xi K_1) = 5.275$. The solution behaviours of the system are shown by perturbing initiation conditions and every solution that is initially close to it eventually converges to E_2 as $t \to \infty$.

Our analysis draws on theoretical findings and numerical simulations, offering valuable insights into achieving strong economic performance while minimizing corruption and unemployment. The model highlights two essential conditions for economic prosperity: effective anti-corruption measures and robust job creation. To achieve this, stakeholders must prioritize comprehensive anti-corruption strategies

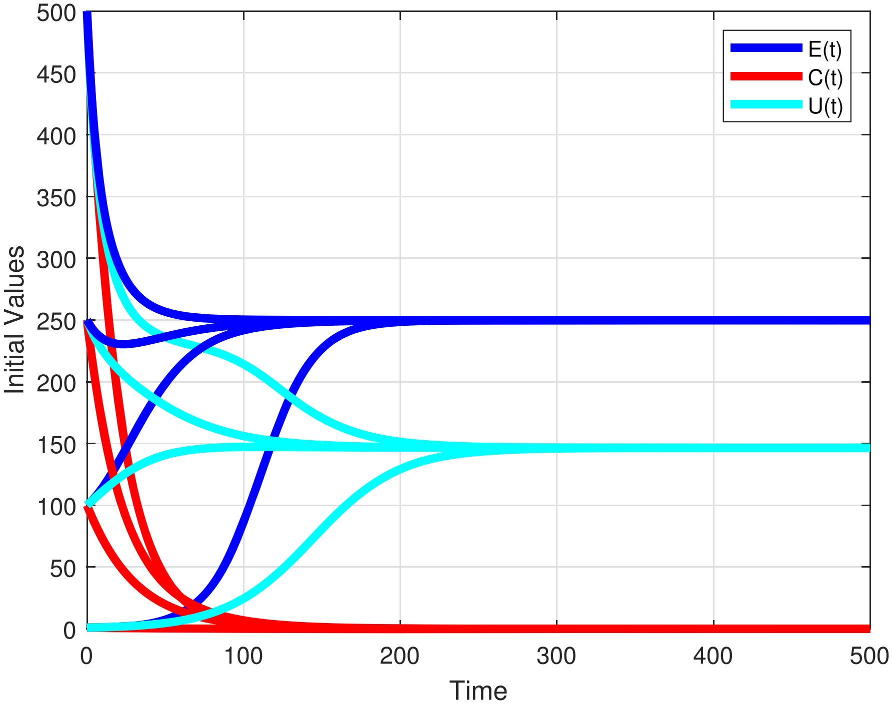

Fig. 2 The stability of corruption-free equilibrium E_3 of the system (1)

that address underlying issues and promote transparency. Additionally, efforts should focus on enhancing job creation and entrepreneurship through training programs and investments in sectors with high job potential. Pursuing these strategies can create a positive feedback loop: effective anti-corruption measures foster a vibrant economy, generating resources for job creation. Increased employment opportunities and entrepreneurial activity further reduce unemployment and deter corruption, ultimately fostering sustainable economic growth in the long term.

We would like to demonstrate the stability of the corruption-free equilibrium $E_3 = (K_1, 0, K_2\left(1 - \frac{\kappa}{r_2}\right) - \xi K_1)$ as proven by Theorem 5. We will be using the following parameter values: $r_1 = 0.059$, $r_2 = 0.0618$, $\xi = \frac{1}{3}$, $\phi = 0.77$, $K_1 = 250$, $K_2 = 250$, $\mu = 0.05$, $\kappa = 0.005$, $a = 1.25$, and $\beta = 0.0001$. We obtain the corresponding eigenvalues of $J(E_3)$ are $\lambda_1 = -0.059$, $\lambda_2 = -0.0362$, $\lambda_3 = -0.0313333$.

Simulations depicted in Fig. 2 confirm the local asymptotic stability of a corruption-free economic state (E_3) predicted by Theorem 5. This state represents full resource utilization ($K_1 = 250$) with no corruption ($C = 0$). However, a key finding is the persistence of unemployment ($U = 146.5$) even under these ideal conditions. The parameter values used (high resource utilization and low corruption) satisfy the stability conditions. All solutions converge to E_3 over time, and the eigenvalues confirm local stability.

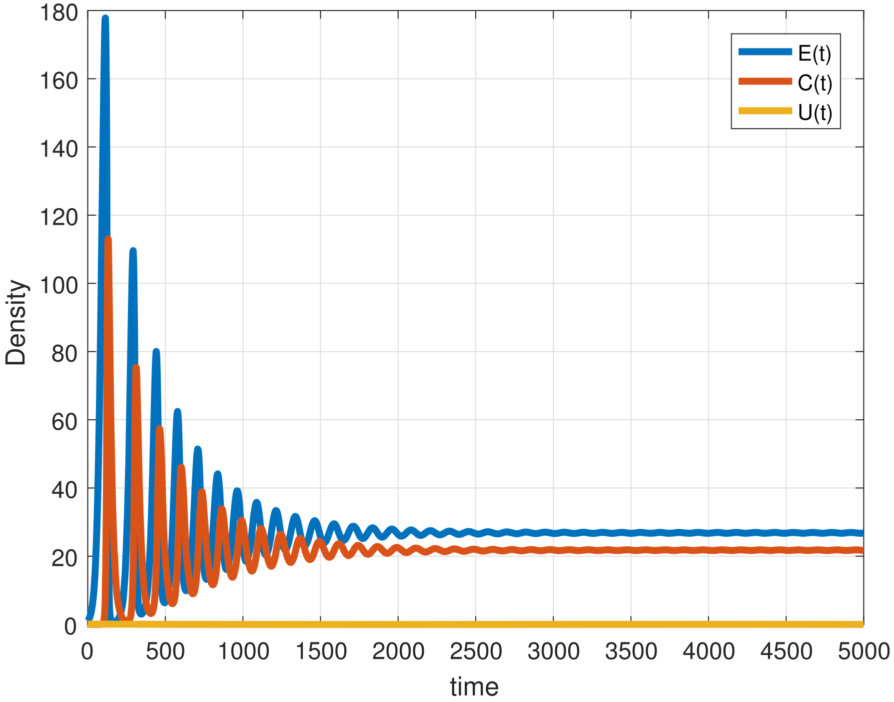

Fig. 3 The time series evaluation of system (1) under the stability conditions of E_4

Economically, this highlights the limitations of solely focusing on corruption control. Factors like skill mismatches (addressed by training programs), automation (requiring job market adaptation), and labour market rigidities can contribute to persistent unemployment. Policies aiming to achieve E_3 need a multifaceted approach. Alongside anti-corruption measures, investments in education, fostering innovation for job creation, and analyzing labour regulations can help address these challenges. Figure 2 underscores the need for a comprehensive strategy for a healthy economy, recognizing that controlling corruption is just one piece of the puzzle.

We now investigate the dynamic stability of the unemployment-free equilibrium, E_4, predicted by Theorem 6. This equilibrium point allows for positive resource density and corruption density while achieving zero unemployment. Specific parameter values are used for this analysis: $r_1 = 0.059$, $r_2 = 0.0618$, $\xi = 1/3$, $\phi = 0.77$, $K_1 = 250$, $K_2 = 25$, $\mu = 0.05$, $\kappa = 0.05$, $a = 0.5$, $\beta = 0.0025$. The eigenvalues $J(E_4)$ are $\lambda_1 = -0.00121196{+}0.0490162i, \lambda_2 = -0.00121196{-}0.0490162i, \lambda_3 = -0.0114933$.

Figure 3 unveils a surprising dynamic around the unemployment-free equilibrium, $E_4(28.27, 22.78, 0)$. This state represents an economy with positive resource utilization and some corruption, yet zero unemployment. The simulations suggest E_4 exhibits spiral stability. While the system deviates from this equilibrium due to external factors, it does not return directly but instead spirals inwards towards E_4 over time, as confirmed by the eigenvalues. Specific parameter values, reflecting job creation rates, corruption rates, and anti-corruption effectiveness, influence this behaviour and align with the predictions of Theorem 6.

Economically, achieving zero unemployment might not be the sole indicator of a perfectly stable system. Figure 3 suggests the possibility of fluctuations in resource utilization and corruption around their average values. The observed spiral could indicate these fluctuations, with corruption levels potentially lagging behind economic activity. This highlights the complexity of maintaining a perfect equilibrium. Moreover, the analysis implies that insufficient anti-corruption measures, even with ample job opportunities, might contribute to this phenomenon. This emphasizes the crucial role of a two-pronged approach: fostering job creation and implementing robust anti-corruption efforts. Strong anti-corruption measures are necessary to prevent these fluctuations and achieve a more stable economic environment, even with low unemployment.

We now investigate the local asymptotic stability of the coexistence equilibrium, E, predicted by Theorem 7. This equilibrium allows for positive resource density, positive corruption density, and positive unemployment density. Specific parameter values are chosen for this analysis: $r_1 = 0.059$, $r_2 = 0.0618$, $\xi = 1/3$, $\phi = 0.77$, $K_1 = 250$, $K_2 = 25$, $\mu = 0.05$, $\kappa = 0.005$, $a = 0.5$, $\beta = 0.0025$. We obtained eigenvalues of the Jacobian matrix (2) at E^* and obtained the corresponding complex conjugate eigenvalues $\lambda_1 = -0.00121196 + 0.0490162i$, $\lambda_2 = -0.00121196 - 0.0490162i$, $\lambda_3 = -0.0335067 + 0.i$.

Simulations in Fig. 4 reveal a fascinating dynamic behaviour around the coexistence equilibrium, $E^*(28.27, 22.78, 13.55)$. This state represents an economy with positive resource utilization, corruption, and unemployment. Interestingly, E^* exhibits spiral stability. While disruptions might cause the system to deviate initially, it does not return directly but instead spirals inwards towards E^* over time. The complex conjugate eigenvalues confirm this mathematically. Specific parameter values used in the simulation, as shown by the inequalities, influence this behaviour. These parameters relate to job creation rates, corruption levels, and the effectiveness of anti-corruption measures. Notably, the observed behaviour aligns with the predictions of Theorem 7, strengthening the theoretical framework.

Building on the findings from Fig. 4, we can glean a deeper economic reality. Even with some unemployment, the system exhibits spiral stability around E^*. This translates to fluctuations around average levels of resource utilization, corruption, and unemployment, with potential lags between these fluctuations. These fluctuations highlight the inherent difficulty of achieving a perfectly stable economic equilibrium. The analysis suggests that insufficient anti-corruption measures and job opportunities might contribute to this phenomenon. This underscores the importance of a two-pronged approach: fostering job creation alongside robust anti-corruption efforts. Strong anti-corruption measures are necessary to minimize these fluctuations and achieve a more stable economic environment, even with some unemployment reduction.

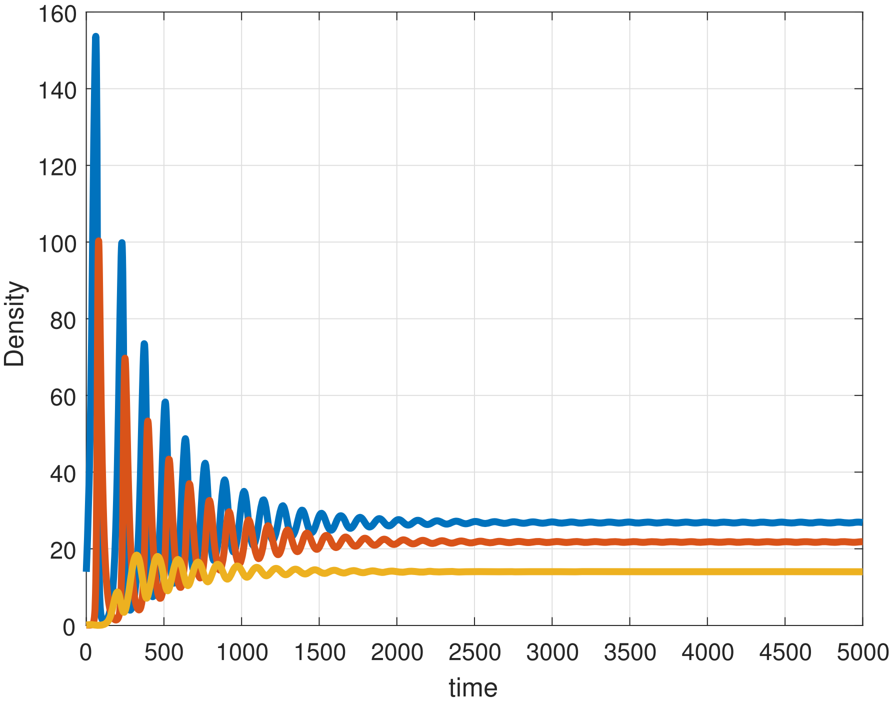

Fig. 4 The time series evaluation of system (1) under stability of condition of E^*

4.2 Sensitivity Analysis of Model Parameters

The impact of economic growth on creating productive jobs is not solely determined by the growth rate itself. It also depends on how effectively that growth translates into opportunities for people to find good jobs [45].

Figure 5 illustrates the economic relationship between resource availability and unemployment density. When new businesses and resource-based jobs are scarce, unemployment density reaches its peak. Conversely, economic growth accompanied by effective job creation significantly reduces the concentration of unemployed individuals. This reinforces a core economic principle: labour market equilibrium. High unemployment density signifies a labour surplus, where there are more job seekers than available positions. Conversely, job creation driven by economic growth helps achieve equilibrium by reducing the number of unemployed. The cited research [45] likely emphasizes the social costs of high unemployment, suggesting it can hinder sustainable economic growth. To achieve a stable and inclusive economy with low unemployment density, it is crucial to balance economic growth with job creation.

Beyond job creation through economic growth strategies that prioritize employment, entrepreneurship among the unemployed population also plays a significant role in reducing unemployment. Research by [46] and [47] highlights the positive impact

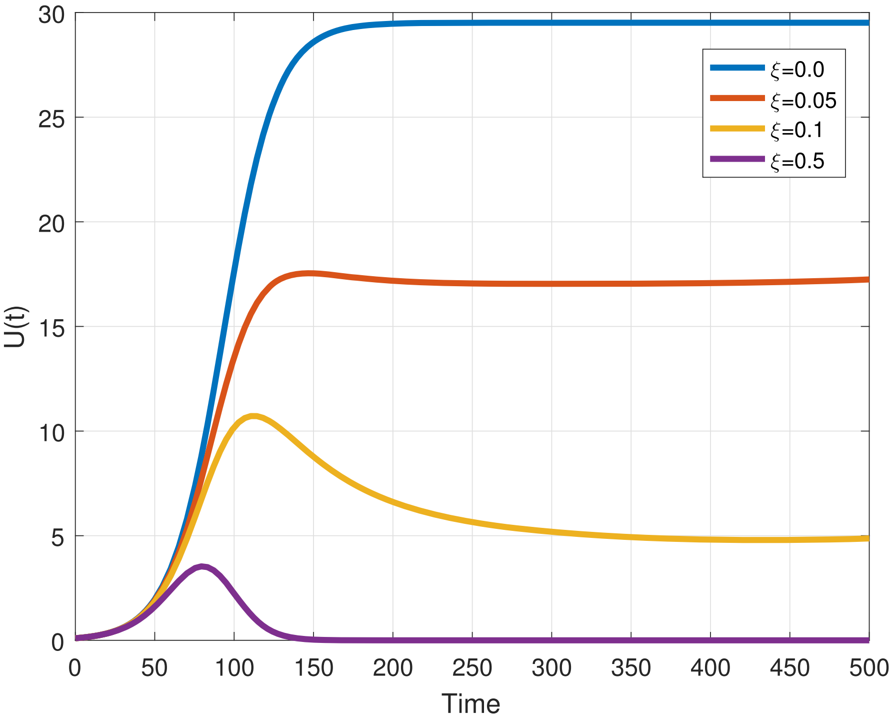

Fig. 5 The impact of economic growth on unemployment crowd density ($U(t)$)

of unemployed individuals becoming productive entrepreneurs. These entrepreneurs not only contribute to their employment but also create new jobs, develop innovative technologies, and boost overall economic productivity.

Figure 6 investigates the impact of new business creation, fueled by individuals transitioning from unemployment to entrepreneurship, on unemployment rates. The results reveal a clear relationship: as the rate of new business creation (represented by the new business density rate) increases, the density of the unemployed population decreases. This finding underlines the critical importance of fostering entrepreneurship among the unemployed. When these individuals do not create new businesses (e.g., Fig. 6 with $\kappa = 0$), unemployment might fluctuate but ultimately remain high. However, when individuals successfully transition to become productive entrepreneurs (e.g., Fig. 6 with $\kappa = 0.05$), unemployment significantly decreases. This is because these entrepreneurs not only secure their employment but also generate new job opportunities for others.

Corruption poses a significant global threat, hindering economic growth and entrepreneurial activity. This instability within various economic systems necessitates the evaluation of effective anti-corruption strategies to enhance economic density.

Simulations based on a mathematical model (Eq. (1)) in Fig. 7 reveal a stark contrast between the economic impact of strong and weak anti-corruption measures. Implementing effective interventions (e.g., $\mu = 0.5$) leads to a flourishing economy, with

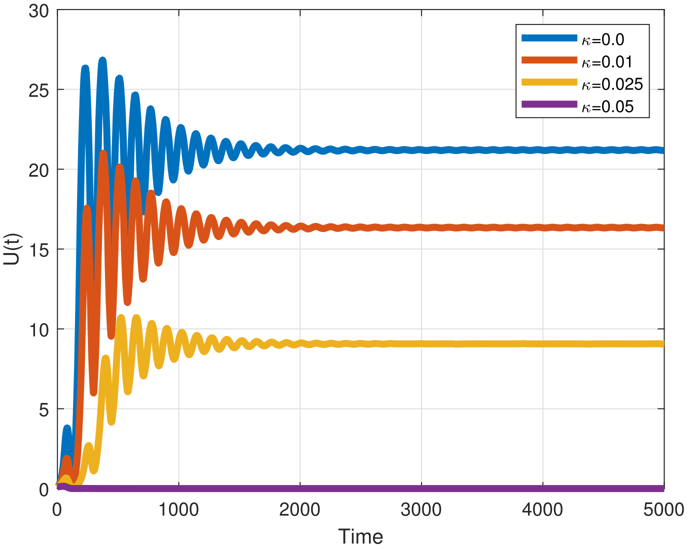

Fig. 6 The roles of new business creation on the unemployed individuals density

economic density reaching its maximum level. This highlights the crucial role of tackling corruption for long-term economic health. Conversely, neglecting corruption (e.g., $\mu = 0$) can be disastrous, leading to eventual economic collapse. The simulations also suggest a connection between anti-corruption efforts, corruption levels, and

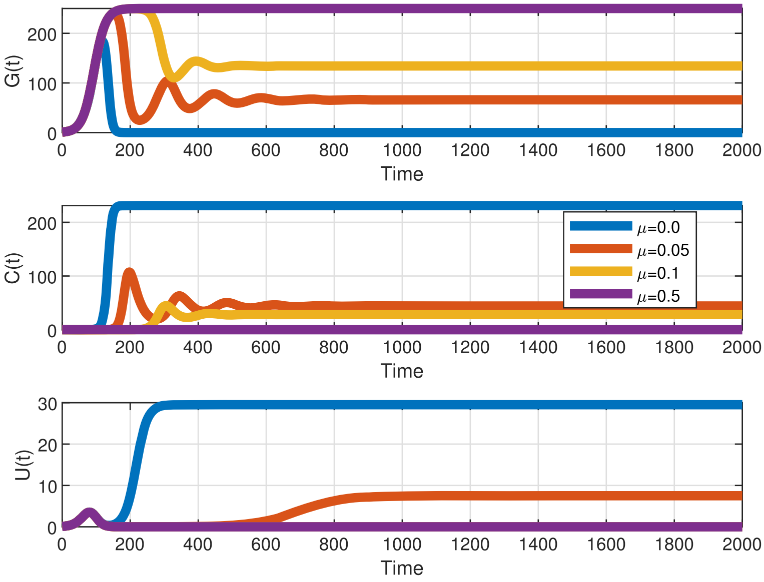

Fig. 7 The role of anti-corruption measure on the system (1)

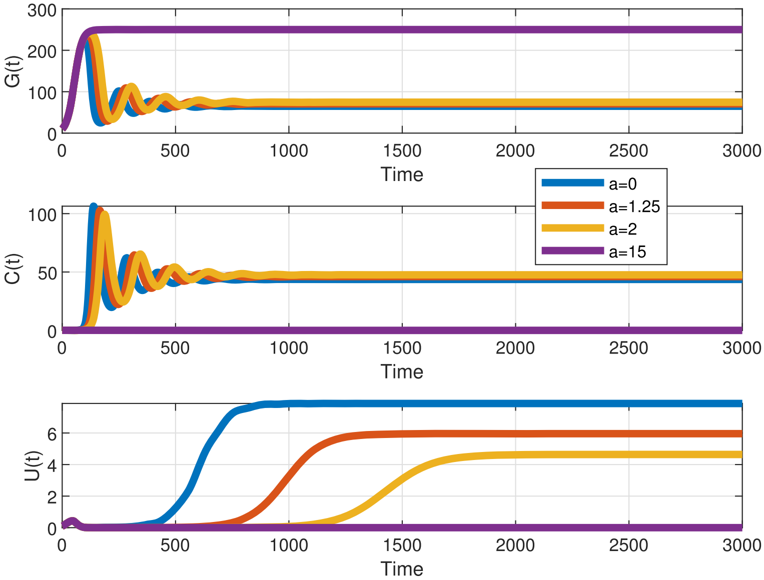

Fig. 8 The impact of corruption handling time on the system (1)

unemployment. As anti-corruption measures increase, both corruption and unemployment decline. However, there might be a point of diminishing returns where further efforts have minimal impact. Overall, Fig. 7 emphasizes that robust anti-corruption measures are essential for a sustainable economy, with the intensity of these measures needing careful calibration for optimal results.

Strong economic institutions are crucial for deterring corruption. Weaknesses in corruption regulation and financial systems create an environment conducive to corruption, allowing it to persist [48]. In this context, we use corruption handling time as a metric to gauge the effectiveness of these systems. Corruption itself has significant economic costs [12]. It distorts economic activity by diverting resources from productive investments towards bribes and rent-seeking behaviour. Additionally, it discourages foreign investment and innovation due to the uncertainty and unfair competition it creates [49]. Weak financial systems can further exacerbate corruption by providing opportunities for money laundering and financial manipulation [50].

Figure 8 reveals a key finding for economic policy: a positive correlation exists between economic density and increased corruption handling time, up to a limit. This suggests that effectively addressing corruption, even if it takes time (e.g., Fig. 8, $a = 15$), ultimately leads to a more robust economy. Research by Mauro [12] supports this, demonstrating a positive impact on economic growth. However, the figure also warns against overly rapid handling in weak systems (e.g., Fig. 8, $a = 0.0$). These systems might prioritize speed over thoroughness, potentially harming the economy and increasing corruption.

The solution lies in a two-pronged approach: (1) proactive anti-corruption regulations, persistently develop strong regulations emphasizing prevention alongside reactive measures, and (2) transparency and resilience, bolster transparency and resilience in all system channels against corruption. Businesses also play a critical role. Implementing rigorous anti-corruption standards safeguards their reputation, fosters trust with stakeholders, and contributes to sustainable economic development.

Economically, corruption distorts resource allocation, discourages investment, and stifles innovation[11]. By tackling corruption effectively, even if it takes time initially, economies can cultivate a stable and predictable environment that fosters long-term economic growth, justifying the investment in robust anti-corruption measures.

5 Conclusion

This study investigated the intricate interplay between economic growth, corruption, and unemployment through a novel mathematical model. The analysis combined theoretical insights with numerical simulations to explore the model's dynamics and their economic implications.

The model identified an ideal scenario, achievable under specific conditions: a flourishing economy with full employment, zero corruption, and maximized resource utilization. However, even without achieving this ideal state, the analysis emphasizes the importance of controlling corruption for economic prosperity. Robust anti-corruption measures were shown to lead to a stable and productive economy, even with some unemployment persisting.

The study explored additional equilibria with unique characteristics. A "corruption-free equilibrium" exists where resource utilization is optimized but some unemployment remains. This highlights the limitations of a singular focus on corruption control and the need for additional measures to address factors like skill gaps and labour market rigidities. Conversely, an "unemployment-free equilibrium" emerges where all unemployed individuals find work, but corruption persists. This scenario emphasizes the importance of job creation alongside anti-corruption efforts. Finally, the model explores a "coexistence equilibrium" where some unemployment exists despite job creation from both economic growth and new businesses.

The sensitivity analysis reinforced the importance of economic growth translating into job opportunities. High economic growth with limited job creation leads to high unemployment. Conversely, creating jobs alongside growth fosters a balanced labour market. The study also found that encouraging unemployed individuals to become entrepreneurs plays a crucial role in reducing unemployment rates.

Recognizing the valuable insights provided by the current model, its limitations due to simplifying assumptions and the exclusion of external factors must be acknowledged. Future research can address this by incorporating more intricate functional forms or agent-based modelling techniques, allowing for a more realistic representation of complexities. Additionally, including external factors like global economic conditions and technological advancements can provide a more comprehensive analysis of how they influence the model's equilibria and stability. Furthermore, exploring the effectiveness of specific policy interventions within the framework can offer valuable insights into how to tackle unemployment and corruption. By addressing these limitations and expanding the model's scope, future research holds the potential to provide a deeper understanding of the interplay between economic growth, corruption, and unemployment, ultimately informing the development of effective policies for sustainable economic development.

Author Contribution All authors contributed equally to this work.

Data Availability No datasets were generated or analyzed during the current study.

Declarations

Competing Interests The authors declare no competing interests.

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