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Modeling Kenyan Economic Impact of Corona Virus in Kenya Using Discrete-Time Markov Chains

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Abstract Since the outbreak of pandemic COVID-19 (Corona virus), many countries have continued to suffer economically leading to massive losses in terms of trillions of dollars globally in terms of trade loses. In reaction to this effect, many countries in the world have taken emergency measures to ensure that the impact does not lead to huge economic and financial implications in terms of rapid recession. In Africa, where many countries have taken measures to deal with global recession to the citizens especially through fiscal and monetary policies, which includes Kenya. In addition, the social economic statues have continued to change instantaneously and stochastically more so after huge number of populations losing their daily informal jobs with new measures to stop the spread of COVID-19 virus. This paper seeks to model the effect of COVID-19 pandemic on Kenyan Gross Domestic Product (GDP) contributors using a Discrete-time Markov Chain Analysis. In addition, the paper seeks to find the ultimate effect of the Covid-19 to the top five key sectors of the Kenyan economy that contributes massively to GDP growth by looking at the proportion of the contributors at steady state. Moreover, the results from this paper should help the government of Kenya as well as global investors to understand different economic stimulus planning packages to launch in the "hard-hit" sectors of the economy to reduce the impact of the potential economic recession. Ultimately, the information should be help in formulating a post COVID-19 economic recovery plan for the Kenyan economy but also act as a benchmark strategy for many other countries in Africa that has economic and financial dynamics similar to that of Kenya.

Keywords: *Discrete-Time Markov Chains, Steady State, Economic Recession, GDP, Covid-19*

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1. Introduction

Since the inception of Covid-19 in China, the economy has been on the turmoil globally [1]. This is because China has a direct correlation with most economies in the world; they depend on it directly or indirectly [2]. While the economic impact of Covid-19 has not only been felt in China and other parts of the European countries [3], Kenya is among those countries who are staring at an economic recession due to the pandemic outbreak of the Covid-19 virus. All economies in the world today has made emergency adjustments as counteractive measures of dealing with the potential threats to their individual GDP growth rates.

On the 13th March, 2020, the government of Kenya confirmed its first ever case of Covid-19 (Corona Virus) following a 27-year-old woman of Kenyan origin who had traveled to the country from USA via the United Kingdom in London. The government had started making preparations since it knew that ultimately the virus would have a huge economic impact once it lands in Kenya. Since this announcement, the economy of Kenya has had huge impact especially from the businesses that has been affected immensely. Two days later, the Kenyan government did prohibit all public gathering leading to even massive economic challenges for the hundreds of thousands of business around the country. While most African countries had been preparing for the Covid-19 virus, most of them lack adequate resources that would enable them attack the eventualities of the virus [4] especially in the existing economic perspectives.

The government has taken some fiscal and monetary measures to deal with economic conditions prevailing in the country: the president had executive orders giving a 100 percent tax relief to those Kenyans who earning less than $230 USD, Pay as you earn commonly known in Kenya as PAYE tax reduction reduced to 25 percent from 30 percent, turnover tax rate reduced to 1 percent from 3 percent for all micro, small as well as medium businesses or enterprises, resident income tax reduction to 25 percent and Value Added Tax 14 percent from 16 percent effective 1st April, 2020 among many other measures. These measures intend to increase the levels of liquidity as well as the velocity of money circulation among Kenyans in a bid to cushion the Covid-19 financial and economic effects among the citizens.

The Central Bank of Kenya offer fiscal and monetary policies such as lowering the original Central Bank Rate 7.25 percent from 8.25 percent to enhance borrowing among Kenyans from the commercial banks operating in Kenya. In addition, the reduction of Cash Reserve Ratio (CRR) for the Kenyan Commercial banks to 4.25 percent from 5.25 percent is an important way of increasing liquidity of the Kenyan commercial banks by $ 360 million USD billion which, in turn, should help in positioning the citizens while offering affordable loan services during any kind of financial needs to majority of the "*financially- distressed Kenyans*". Many travel restrictions have been reduced to vital hotels in Kenya, tourism as well as horticulture industries are now facing huge challenges especially with the restrictions from all over the world. In the last couple of days, many hotels are closing especially after the government announced a dusk to dawn curfew that has left many businesses that depends on the nocturnal activities to survive on its knees struggling with cash flows to stay afloat on the market with soaring wage bills to pay despite the business being down financially.

The Kenyan government needs to understand on the extend in which the Covid-19 virus will affects its key economic areas thus helping the fiscal and monetary planners to understand how the economic dynamics are changing thus enabling them to come up with a formidable plan that would help Kenyans get back on their knees once the pandemic virus is over. The aim of this paper is to predict the economic changes that are likely to be experienced in terms of GDP contributions from the main economic sectors of the country. The papers also models the GDP contributors using a discrete-time Markov Chains process to model the events at the same time determine what happens in the long run once the pandemic is gone at the same time offering an avenue for the economists and financial analysts to propose proper financial and economic recovery measures for the future. Those African countries with similar economic dynamics can apply the findings to assist in economy recovery plans especially after the potential economic recession during the year.

2. Kenyan Economic Modeling

2.1. An Overview of Economics Conceptual Framework

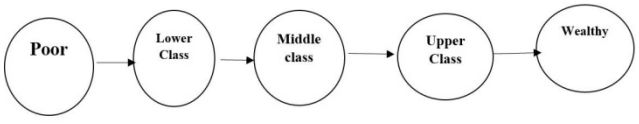

Figure 1. Social-Economic Status in Kenya

From the above social economic groupings (Figure 1), we will assume the following states of nature as follows;

- **Poor**- A person earning less than $1.25 a day (*s*1)
- **Lower Class**- A person Earning from $1.25 to $20 a day ($s_2$)
- **Middle Class**- A person Earning from $20 to $50 a day ($s_3$)
- **Upper Class**- A person earning from $50 to $150 a day ($s_4$)
- **Wealthy**- A person making more than $150 a day ($s_4$)

In this paper, we will note that the persons in the above states of nature can move from state to another with no absorbing state in the probability transition matrix. This means that a person from one state can easily move from one state to another within a discrete-time period.

2.2. Discrete-Time Markov Chains Mathematical Preliminaries

A Markov chain can be defined as a stochastic model that describes a sequence of all probable events that gives the probability of every event depending only on a given state attained in the preceding event [5]. This stochastic model can either be in discrete time model or a continuous-time model depending on the nature of the study being undertaken by the researcher. For the purposes of this paper, we will assume that the Markov Chain is on a finite or countable state space (discrete-time model). A discrete- time Markov Chain in this cases is a sequence of identically and independently random variables namely X_1, X_2, X_3..., which will only have the Markov property if probability or likelihood of moving from one state to another only depends on its present state as opposed to the previous states (ignoring the filtration process up to the given time period) [6].

We can consider a discrete-time Markov process $(Z_n)_{n\varepsilon N}$ that takes in discrete values in a discrete state space Θ where $\Theta\varepsilon\mathbb{Z}$.

$$P\left[Z_{n+1}=z/Z_1=z_1,Z_2=z_2,Z_3=z_3,...,Z_n=z_n\right] = P\left[Z_{n+1}=z/Z_n=z_n\right] \quad (1)$$

provided all the initial conditions are defined as follows;

$$P\left[Z_1=z_1,Z_2=z_2,...,Z_n=z_n\right]>0. \quad (2)$$

We will assume that the discrete-time Markov chains do not have independent increments during the modeling process at the same time no absorbing states in the probability transition matrix during the study.

2.3. Probability Transition Matrix Model

In the paper, we can model the social-economic statutes using a Discrete-time Markov Chain Analysis model [7]. We start by introducing the concept through definition of $P_{x,t}^{ij}$.

Given that the social economic status or groupings in Kenya can be modeled by a probability transition matrix as illustrated below;

$$P_{x,t}^{ij}=\begin{array}{c|cccc} & s_1 & s_2 & \cdots & s_n \\ s_1 & p_{11} & p_{12} & \cdots & p_{1n} \\ s_2 & p_{21} & p_{22} & \cdots & p_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ s_n & p_{m1} & p_{m2} & \cdots & p_{nn} \end{array}$$

We can define the probability $P_{x,t}^{ij}$ as the probability that a given population of a social economic grouping being in i at $x + t$ given that was in state j at time x. For example, p_{11}, shows the probability that a person living in Kenya will be in social economic status in state 1 and still be in state 1 after a given time period from x to $x + t$.

From the model, we can denote s_1, $s_2 ... s_n$ are the given states of nature or the social-economic groupings of the Kenyan population.

In addition, we can model the top five economic contributions to the Kenyan economy as a vector, Π, which is defined as;

$$\Pi=\left(\pi_1,\pi_2,\pi_3,...,\pi_n\right) \tag{3}$$

where the values of $\pi_1,\pi_2,\pi_3,...,\pi_n$ are proportions such are summed to one, which is a stationary distribution;

$$\pi_1+\pi_2+\pi_3+\pi_n=1. \tag{4}$$

In this paper, we will use the discrete-time Markov Chains in predicting the value or vector of P from time $t=1,2,3,...,n$ where n is a large number $\left(n\to\infty\right)$.

$$\Pi^{(2)}=\Pi * P_{x,t}^{ij} \tag{5}$$

$$\Pi^{(3)}=\Pi^{(2)} * P_{x,t}^{ij} \tag{6}$$

$$\cdots\cdots\cdots$$

$$\Pi^{(n)}=\Pi^{(n-1)} * P_{x,t}^{ij} \tag{7}$$

From the Markov chains analysis above, we can simplify the social-economic statutes in Kenyan as in the economic framework. The top five sectors that contributes to economic growth (in terms of GDP input) in Kenya includes Agriculture, Tourism, building and construction, infrastructure development, and manufacturing [8] Through the above five key sectors of the economy, we can simplify the vector matrix of proportion as Π. However, the probability transition matrix, $P_{x,t}^{ij}$ will be given as:

$$P_{x,t}^{ij}=\begin{array}{c|ccccc} & s_1 & s_2 & s_3 & s_4 & s_5 \\ s_1 & p_{11} & p_{12} & p_{13} & p_{14} & p_{15} \\ s_2 & p_{21} & p_{22} & p_{23} & p_{24} & p_{25} \\ s_3 & p_{31} & p_{32} & p_{33} & p_{34} & p_{35} \\ s_4 & p_{41} & p_{42} & p_{43} & p_{44} & p_{45} \\ s_5 & p_{51} & p_{52} & p_{53} & p_{54} & p_{55} \end{array}$$

where Poor is s_1, Lower Class is s_2, Middle Class is s_3, Upper class is s_4, and Wealthy is s_5 as defined earlier.

2.4. The Steady State Analysis

For the purposes of planning, it is important to find out the proportion of the Kenyan Economic contributions of Agriculture, Tourism, building and construction, infrastructure development, and manufacturing that will be at the Equilibrium State [6] From the equation (5), we can define a steady state as;

We can assume that

$$\begin{aligned}\Pi_i^{(j)} &= \lim_{n\to\infty} P\left[Z_n=j/Z_0=i\right] \\ &= \lim_{n\to\infty} P\left[Z_{n+1}=j/Z_0=i\right].\end{aligned} \tag{8}$$

using the concept of Bayes theorem

$$= \lim_{n\to\infty}\sum_{l\in S} P\left[Z_{n+1}=j/Z_n=l\right] * P\left[Z_{n+1}=j/Z_0=i\right]$$

$$= \lim_{n\to\infty}\sum_{l\in S} P\left[Z_n=l/Z_n=i\right]$$

$$= \sum_{l\in S} P_{x,t} * \lim_{n\to\infty}\left[Z_{n+1}=l/Z_n=i\right]$$

$$= \sum_{x,t\in S} \Pi_i^{(j)} * P_{x,t}^{ij}, x,t\in S$$

hence, we obtain that

$$\Pi^{(n)}_{n\mapsto\infty}=\Pi^{(n-1)}_{n\mapsto\infty} * P_{x,t}^{ij} \tag{9}$$

$$\Pi=\Pi * P_{x,t}^{ij}. \tag{10}$$

Ultimately, we will apply the transition probability matrix on the proportion to obtain;

$$\left(\pi_1,\pi_2,\pi_3,\pi_4,\pi_5\right)$$

$$=\left(\pi_1,\pi_2,\pi_3,\pi_4,\pi_5\right)\begin{array}{c|ccccc} & s_1 & s_2 & s_3 & s_4 & s_5 \\ s_1 & p_{11} & p_{12} & p_{13} & p_{14} & p_{15} \\ s_2 & p_{21} & p_{22} & p_{23} & p_{24} & p_{25} \\ s_3 & p_{31} & p_{32} & p_{33} & p_{34} & p_{35} \\ s_4 & p_{41} & p_{42} & p_{43} & p_{44} & p_{45} \\ s_5 & p_{51} & p_{52} & p_{53} & p_{54} & p_{55} \end{array}$$

From the above valuation in steady state, we can form five simultaneous equations as follows:

$$\pi_1=\pi_1 p_{11}+\pi_2 p_{21}+\pi_2 p_{31}+\pi_2 p_{41}+\pi_2 p_{51}$$

$$\pi_2=\pi_1 p_{21}+\pi_2 p_{22}+\pi_2 p_{23}+\pi_2 p_{24}+\pi_2 p_{25}$$

$$\pi_3=\pi_1 p_{31}+\pi_2 p_{32}+\pi_2 p_{33}+\pi_2 p_{34}+\pi_2 p_{35}$$

$$\pi_4=\pi_1 p_{41}+\pi_2 p_{42}+\pi_2 p_{43}+\pi_2 p_{44}+\pi_2 p_{45}$$

$$\pi_5=\pi_1 p_{51}+\pi_2 p_{52}+\pi_2 p_{53}+\pi_2 p_{54}+\pi_2 p_{55}$$

$$\pi_1+\pi_2+\pi_3+\pi_4+\pi_5=1 \text{ or } \sum_{i=1}^{5}\pi_i=1$$

In the paper, our work will be to determine the value of vector, Π, which will be very important in analysis the new post-Covid-19 proportions to the contributions to GDP in the country. The proportion will be a stochastic process since the value will be changing as the economic dynamics change every day with the new infections being confirmed from the population. With the determination of the value or vector of Π [9] the government and policy makers can decide on the best appropriate economic measures to take when dealing with the effects currently experienced within the country as well as globally.

The values of π_1, π_2, π_3, π_4 and π_5 will be proportion of the *GDP* contributions at the given equilibrium state in the

long run, which will provide the vital information on how the Covid-19 virus have had an economic impact on the livelihood of the Kenyans in terms of how it affects the top five economic contributions to the citizens.

3. Data Analysis

The data available on the economic impact of Covid-19 in Kenya can be found in the website (https://www.statista.com/state of-economic-sectors-in-the-gdp-in-kenya/). From the data, we will do an analysis to come up with the Vector of proportions to the economic contributions to the GDP of Kenya [10].

3.1. Economic Sectors According to the GDP Contributions

We can summarize the top five economic contributions to the economic growth as follows;

Table 1. Economic sector Vs proportion to GDP in Kenya

Economic Sector	% Contribution to GDP
Agriculture Sector =X_1	24.15%
Tourism Sector =X_2	9.85%
Building & Construction=X_3	10.25%
Infrastructure development=X_4	12.56%
Manufacturing=X_5	9.30%

The Economic sector Vs proportion to GDP in Kenya can be summarized in weight index as illustrated in the table below;

Table 2. Weight Index per GDP Contribution

Economic Sector	Weight Index
Agriculture Sector =X_1	$\frac{X_1}{\sum_{i=1}^{5}\pi_i}=\frac{24.15}{66.11}=0.36$
Tourism Sector =X_2	$\frac{X_2}{\sum_{i=1}^{5}\pi_i}=\frac{9.85}{66.11}=0.15$
Building & Construction=X_3	$\frac{X_3}{\sum_{i=1}^{5}\pi_i}=\frac{10.25}{66.11}=0.16$
Infrastructure development=X_4	$\frac{X_4}{\sum_{i=1}^{5}\pi_i}=\frac{12.56}{66.11}=0.19$
Manufacturing=X_5	$\frac{X_5}{\sum_{i=1}^{5}\pi_i}=\frac{9.3}{66.11}=0.14$

The vector of the economy will be written as a vector,

$$\begin{aligned}\Pi &= (\pi_1,\pi_2,\pi_3,\pi_4,\pi_5)\\ &= (0.36,0.15,0.16,0.19,0.14)\end{aligned} \quad (11)$$

3.2. Proportion of the Social-Economic Statuses in Kenya

The proportion of the different social economic statutes in the Kenyan population can be summarized as follows;

Table 3. Social Economic Groupings

Economic Sector	% of the population
Poor	42.1%
Lower Class	40.25%
Middle Class	11.65%
Upper Class	5%
Wealthy	1%

The source of data is http://www.knbs.or.ke. From the above two tables, we will use the Discrete-time Markov Chain analysis. By using the values from the Table 3, we can fill the probability transition matrix below as follows;

$$P_{x,j}^{ij}=\begin{array}{c}\\ s_1\\ s_2\\ s_3\\ s_4\\ s_5\end{array}\begin{array}{c}\begin{array}{ccccc}s_1 & s_2 & s_3 & s_4 & s_5\end{array}\\ \begin{bmatrix}0.42 & 0.40 & 0.12 & 0.05 & 0.01\\ 0.42 & 0.40 & 0.12 & 0.05 & 0.01\\ 0.42 & 0.40 & 0.12 & 0.05 & 0.01\\ 0.42 & 0.40 & 0.12 & 0.05 & 0.01\\ 0.42 & 0.40 & 0.12 & 0.05 & 0.01\end{bmatrix}\end{array}$$

We will determine what happens at steady state by looking at what happens after a long run.

$$(\pi_1,\pi_2,\pi_3,\pi_4,\pi_5)$$

$$=(\pi_1,\pi_2,\pi_3,\pi_4,\pi_5)\begin{bmatrix}0.42 & 0.40 & 0.12 & 0.05 & 0.01\\ 0.42 & 0.40 & 0.12 & 0.05 & 0.01\\ 0.42 & 0.40 & 0.12 & 0.05 & 0.01\\ 0.42 & 0.40 & 0.12 & 0.05 & 0.01\\ 0.42 & 0.40 & 0.12 & 0.05 & 0.01\end{bmatrix}$$

$$\pi_1=0.42\pi_1+0.42\pi_2+0.42\pi_3+0.42\pi_4+0.42\pi_5$$

$$\pi_2=0.40\pi_1+0.40\pi_2+0.40\pi_3+0.40\pi_4+0.40\pi_5$$

$$\pi_3=0.12\pi_1+0.12\pi_2+0.12\pi_3+0.12\pi_4+0.12\pi_5$$

$$\pi_4=0.05\pi_1+0.05\pi_2+0.05\pi_3+0.05\pi_4+0.05\pi_5$$

$$\pi_5=0.01\pi_1+0.01\pi_2+0.01\pi_3+0.01\pi_4+0.01\pi_5$$

$$\pi_1+\pi_2+\pi_3+\pi_4+\pi_5=1.$$

We can rearrange the above six equations as follows to solve easily;

$$-0.58\pi_1+0.42\pi_2+0.42\pi_3+0.42\pi_4+0.42\pi_5=0$$

$$0.40\pi_1-0.60\pi_2+0.40\pi_3+0.40\pi_4+0.40\pi_5=0$$

$$0.12\pi_1+0.12\pi_2-0.88\pi_3+0.12\pi_4+0.12\pi_5=0$$

$$0.05\pi_1+0.05\pi_2+0.05\pi_3-0.95\pi_4+0.05\pi_5=0$$

$$0.01\pi_1+0.01\pi_2+0.01\pi_3+0.01\pi_4-0.99\pi_5=0$$

$$\pi_1+\pi_2+\pi_3+\pi_4+\pi_5=1$$

The six simultaneous equations can be solved using a mathematical software or [11] method to obtain the definitive values of $\Pi = (\pi_1, \pi_2, \pi_3, \pi_4, \pi_5)$.

4. Results

From the analysis of the results, we have found that the values of Π are as follows

$$\Pi = \begin{pmatrix} \pi_1 = 0.28, \pi_2 = 0.13, \\ \pi_3 = 0.14, \pi_4 = 0.16, \pi_5 = 0.13 \end{pmatrix} \quad (12)$$

We can find;

- the proportion of π_1 = 0.28 has reduced remarkably from the previous percentage of 0.36.
- the proportion of π_2 = 0.13 has reduced remarkably from the previous percentage of 0.15.
- the proportion of π_3 = 0.14 has reduced remarkably from the previous percentage of 0.16.
- the proportion of π_4 = 0.16 has reduced remarkably from the previous percentage of 0.19.
- the proportion of π_5 = 0.13 has reduced remarkably from the previous percentage of 0.14.

The economic implications of the Covid-19 have had a negative impact on all economic sectors of the country with the agriculture being the hardest to hit. This is follows by Tourism Sector, Building & Construction, Infrastructure development, while Manufacturing are the least affected being negligible.

Table 4. Pre Vs Post-Covid-19 Sectors Contributions Percentages to GDP Growth

Sector's	Pre-Covid-19 %	Post Covid-19 %
Agriculture Sector	24.15%	18.5%
Tourism Sector	9.85%	8.50%
Building & Construction	10.25%	9.15%
Infrastructure development	12.56%	10.5%
Manufacturing	9.30%	8.45%

5. Conclusion

It is important to note that from Table 4, the Covid-19 have had a negative impact on the Kenyan GDP contributors massively when one analyzes the percentages. For example, Agricultural sector reduced from 24.15% to 18.5% given that it contributed massively for the employment of Kenyan as far as economic growth is concerned. Tourism sector is also affected from 9.85 percent to 8.50 percent, Building and Constriction is another sector affected since Kenyans do not surplus income to invest in the sector thus reducing to 9.15% from a high of 10.25% contribution to the economy. While the government had to halt some of the infrastructural development as a result of Covid-19, the percentages changed from 12.56% before the Corona virus to a low of 10.5%. The Manufacturing sector is one of the Key sectors of the Big Four agenda of the current government regime suffered a huge dip in contribution to the GDP to 8.45 % from 9.3% due to the Corona Virus.

From the results on the impact of economic dynamics of the country, it is easy to note that the rates in terms of proportions have reduced compared to the rates on equation (0.0.12). When the proportions are multiplied by the original the projected aggregate GDP amounts before the existence of Covid-19 virus, then the totals are tabulated in the Table 4.

From the above research, it is important for the Kenyan government to come up with fiscal and monetary policies as well as measures that can protect the various sectors of the economy if it has to remain as the top Eastern African economic powerhouse at the same time still be among the competitive countries in Africa [12] especially when dealing with trans-African trade. China has made huge economic impact not only in Kenya but also many other countries in Africa in terms of cheap loans through their development agendas. While some of the economic projects that the government lately have been good to the development of Kenya in its economic growth agenda, these affected sectors must be reviewed for a recovery from the potential economic recession.

While the government has to continue improving the levels of liquidity among the population, it is important that legislation needs to be put in place to deal with the specific affected sectors by the Covid-19 infections especially at micro levels of Kenyan families. A special fund for those who were directly affected by the virus is vital for faster and systematic economic recovery.

The research should help the government make proper planning options for its citizens during the post- Covid-19 pandemic. However, the research could be extended to many parts of the economy to ascertain the general effects of Covid-19 not only to the top five sectors of the economy but also many others parts of it for absolute economic recovery without having to concentrate on only a small part of it.

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