PUBLIC HEALTH POLICY STANCE OPTIONS IN RESPONSE TO COVID – 19: AN EVOLUTIONARY GAME THEORY MODELLING APPROACH

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Abstract

The dynamics of COVID-19 pandemic calls for urgent policy questions that must be addressed with empirical results, since the efficacy of vaccines is still highly debatable and the rate of mutation is mostly novel. Immediate policy options such as quarantines, movement restrictions, self-isolation and physical distancing have been attempted across the globe, and empirical evaluations of their effectiveness are difficult with such an unpredictable virus. The study considered an evolutionary game approach to Covid-19 interventions by South Africa and Zimbabwe, where a social learning path in an imitation dynamic game was hypothesised and established. The results suggested that restrictions increased and decreased the rate of positive cases at different phases. A possibility of natural herd immunity was also noted. A public centred approach to future restriction and stringent measures was recommended.

Key words: Covid-19, Health policy, Game Theory Modelling

INTRODUCTION

The Coronavirus Disease of 2019 (Covid-19) pandemic has caused more than 213 000 000 confirmed cases and more than 4 400 000 deaths across the globe as of 24 August 2021 (WHO, 2021). On the same date, Zimbabwe had an accumulated case roll of 123 000 cases and 4 293 deaths while South Africa was at 2 700 000 confirmed cases against 79 584 deaths. The attention to trends of Covid-19 statistic are drawing traction on various health policies compounded with high experimentations. Among public-health strategies aimed at suppressing and controlling the spread of the virus (Anderson, et al., 2020) such as quarantines, movement restrictions, self-isolation, physical distancing and vaccination; strict stay-at-home orders have been essential policy tools (Coates, et al., 2020). Detrimental strict orders have severe economic costs, such as businesses closure, reduced services, and reduced employment time which reduces people’s incomes (Kabir and Tanimoto, 2020). What is of paramount importance is to identify the most probable effective way of curbing the virus without gambling through all possible strategies so as to reduce adverse effects of mixed detrimental strategies. The policy response to Covid-19 was centered on restrictions of movements such that in Zimbabwe a 21-day national lockdown was declared, starting on the 30th of March 2020. By the 25th of May 2020, two months after initial lockdown, Zimbabwe had 56 confirmed cases, including 27 active cases, 4 deaths and 25 recoveries. On an earlier date, the 23rd of March 2020, South Africa had announced a national 21-day lockdown beginning on 27 March to 16 April 2020. By 24 March 2020, all nine South African provinces had confirmed cases. The country’s first death was announced on 27 March 2020. Policy responses were seemingly symmetric between these two countries. The table below presents a sequential health policy coordination between South Africa and Zimbabwe from March 2020 to July 2021.

Table 1: First Wave to Third Wave Sequential Policy Interventions

<table>
<thead>
<tr>
<th>Waves</th>
<th>South Africa (Player 1)</th>
<th>Zimbabwe (Player 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Wave</td>
<td>23 March 2020 – A tight 21 day National</td>
<td>30 March 2020 - The Zimbabwian government</td>
</tr>
<tr>
<td>(Mar 2020</td>
<td>Lockdown announced</td>
<td>announces a Level 1 lockdown for a period</td>
</tr>
<tr>
<td>to Nov 2020)</td>
<td></td>
<td>of 21 days to curb the spread of COVID-19.</td>
</tr>
<tr>
<td></td>
<td>09 April 2020 – South Africa announced that</td>
<td>19 April 2020 - Lockdown extended by a</td>
</tr>
<tr>
<td></td>
<td>a nationwide lockdown set to expire on April</td>
<td>further 14 days</td>
</tr>
<tr>
<td></td>
<td>17 has been extended by two weeks to</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thursday, April 30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>01 May 2020 - Level 4 began by allowing</td>
<td>03 May 2020 - Zimbabwe has been under Level</td>
</tr>
<tr>
<td></td>
<td>residents to exercise outdoors and some</td>
<td>1 lockdown for five weeks. National lockdown</td>
</tr>
</tbody>
</table>
businesses to reopen.

13 May 2020 – Intentions to ease lockdown announced.
12 July 2020 – The alcohol ban was reintroduced along with a new curfew from 21:00 until 4:00.
15 August 2020 – Curfew hours relaxed
16 September 2020 – Further lowering of restrictions announced.
11 November 2020 – International travelling allowed.

Second Wave (Dec 2020 to April 2021)  
28 December 2020 – Partial lockdown announced, introduced a curfew from 9 pm to 6 am, the ban on sale and transport of alcohol, closure of public amenities
01 February 2021 – First Shipment of vaccines received and vaccination commences.

Third Wave (May 2021 to Aug 2021: Present date of authorship p)  
30 May 2021 – Tight lockdown measures introduced.
15 June 2021 – Further measure introduced, reinforced by more measures on 27 June 2021.
11 July 2021 – Continuation of lockdown measures announced.
24 August 2021 – Number of people fully vaccinated: 4,983,911 (8.5%)  
2021 – 30-day curfew introduced.
13 January 2021 - Traditional funerals were banned
13 June 2021 - Localised lockdowns introduced.
29 June 2021 - Imposed a dusk to dawn curfew, banned inter-city travel and cut business hours
14 July 2021 – Government extends lockdown to vaccinate 1 000 000 people.
24 August 2021 – Number of people fully vaccinated: 1,483,968 (9.8%)

Sources: Dzobo, M, I Chitungo and T Dzinamarina (2020); GoZ (2020); Ramaphosa (15 March 2020); Evans (2020) Mkhize (2021); Moultrie, et al. (2021); WHO (2020); Pillay-van Wyk, (2020); Mueller (2021); Bradshaw (2021); Crisp (2021); Reynolds (2020); York (2021); WHO (2021); Olander (2021).

This shows that quite a number of strategies were swiftly introduced in order to fight Covid-19. These include adoption of vaccines, community engagement, introduction of lockdown, quarantining of returns from outside among others. What is of paramount importance is whether the policies were equally effective in these countries and if the systematic coordination was of much relevance in guiding future health policy stance.

LITERATURE

The study on Covid-19 requires a proper epidemiological analysis. Epidemiology is the branch of medical science dealing with the incidence, distribution, and control of diseases in a population, with an aim to identify the factors driving the behaviour of a disease. The emergence and worldwide spread of repeated pandemics as well as severe modern epidemics have become serious threats to mankind. Literature is awash with methods of evaluating the potential methods for controlling the breakout and spreading of these epidemic diseases. Econometric modelling is one of the important tools in analysing the spread and control of infectious diseases bearing in mind the key factors governing the development of a disease, such as transmission and recovery rates which can be used to predict how the disease will spread over time. For an in-depth analysis of the behaviour of epidemics, various models of non-linear ordinary differential equations have been studied by different of scholars (Podder, et. al. 2007; Kabir and Tanimoto, 2019; Kuga, Tanimoto and Jusup, 2019).

The novel Covid-19 analysis presents a situation that can be hypothesised as an evolutionary game theory. This is a theory combining game theory analysis and dynamic evolutionary process analysis. Evolutionary game theory has its foundations in the theory of biological evolution. The theory divorces itself from the classical game theory in economics which assumes conditions of rationality and postis a human behaviour of seeking to achieve the balance of game through trial and error. The theory is, therefore, in a better position to analyse and solve a complex of factors such as social habits, norms, institution and the problems in the process of spontaneous evolution.

The novelty of the pandemic situation puts the government and the public’s awareness of the epidemic situation in a constantly changing process. This also makes the response strategies adopted be contained in a process of dynamic adjustment. The choice of participants are subject to the “bounded rationality” hypothesis that the participants of evolutionary game adopt imitation behaviour. What matters most in the evolutionary game analysis is to determine the mode of learning and strategy adjustment of the government, and the public.
during the development of the pandemic. Following the evolutionary game theory, the interaction between the government and the public was coerced during the prevention and control of Covid-19. These became the dynamic evolutionary process of the two players’ repeated game over time which should reach a certain steady state.

Several scholars have studied the epidemic prevention and control from the perspective of the government intervention and the public behaviour. Scholars point out that government intervention measures (Zhang, 2003; Li and Che, 2014; Sega, et al., 2015; Zheng, Wu and Li, 2016), cautious attitude towards epidemic (Kleczkowski, at el., 2015), trust in information (Cui, et al., 2017) and risk awareness (Poletti, Ajelli and Merler, 2011) will affect the control of epidemic. Moreover, the effectiveness of the new management model of the government (Taherkhani and Farshadpour, 2017) and how to control the spread of infectious diseases effectively from the perspective of law enforcement (Qi and Chen, 2009) have been studied. From the perspective of the government and the public, the above scholars have analysed and summarized the prevention and control of the epidemic by using qualitative methods at the macro level, providing experience for the study of the COVID-19 epidemic.

In addition, some scholars have used Susceptible-Infected-Recovered (SIR) model (Poletti, Ajelli and Merler, 2011), generalized stochastic Petri net model and equivalent Markov chain model (Li, Wang and Qiao, 2014), propagation dynamics model (Endo, Ejima and Nishiura, 2018), and other mathematical tools to analyse major public health events. Li, Sun and Zhen (2011) studied an epidemic model with both diffusion and migration. Jin and Li (2018) constructed an evolutionary game model based on the credibility of the government and the trust of the people. Zu et al., (2015) evaluated the effectiveness of border quarantine, isolation, treatment and other measures to prevent influenza by establishing a computer epidemic model. Sun and Zhang (2016) built a disease transmission control model based on the spread force, and simulated the spread process of the disease to build an infection tree, and proposed the target immune algorithm to provide support for the emergency management of disease control. Mei, He and Zhu (2016), introduced spatial information, urban traffic, individual behavior and other factors into the urban air infectious disease diffusion model, and verified the effectiveness of the model by simulating the spread of infectious diseases with a simulation system.

These studies give a foundation for this study by using an econometric model though further models still need to be further optimized. Since the global outbreak of Covid-19 in 2020, some scholars have researched the epidemic from the aspects of clinical characteristics and bio-informatics. Zhu et al. (2020), reviewed the clinical and chest imaging features of Covid-19 and compared them with other infectious and non-infectious diffuse lung diseases to find clues for the diagnosis of Covid-19 to ensure accurate diagnosis and treatment. Chen et al., (2020), identified a novel human coronavirus based on RNA from two cases of pneumonia in Wuhan in 2019. Chen et al., (2020) carried out bioinformatics analysis on the viral genome of a patient infected with Covid-19 and compared it with other coronavirus genomes to provide a basis for studying the pathogenesis, optimal diagnosis, antiviral and vaccination strategies of the disease. Yang et al., (2020) made a comparative analysis of the SARS pandemic and the 2019-nCoV. Combined with the lessons of SARS epidemic, the nucleic acid sequence can be determined and isolation strategy can be adopted quickly. The above studies mainly compare and analyze the Covid-19 with other pulmonary diseases. There are few studies involving evolutionary games and government intervention in Covid-19.

These above studies mainly focus on qualitative analysis or quantitative analysis but there are few studies on modelling and forecasting the development of Covid-19 using evolutionary game from the perspective of the government.

**METHOD AND DATA**

In an evolutionary game theory, the interaction between the policy stances of the two ideally coordinated governments which share the same border and common trade patterns will inevitably occur during the prevention and control of major epidemics. Similarly, the interaction with its citizens in face of Covid-19 has its pay-off. These interactions can clearly be a game process. Assume that the strategy set of Government I (One) is "Restrict" strategy (R) and "Laissez-faire" strategy (L), that is, GI = {R, L}. Similarly, the reaction of Government II is "Restrict" strategy (R) and "Laissez-faire" strategy (L), that is, G2 = {R, L}. The "Restrict" strategy mainly refers to a series of measures taken by the government to actively respond to the epidemic situation, such as large-scale screening and isolation for close contacts and suspected exposed persons of Covid-19, strict epidemic reporting, strengthening the management of medical institutions and targeted treatment. The "Laissez-faire" strategy means that the government is indifferent to the Covid-19 epidemic. However given that the governments have been taking an active restrict approach, though at different levels, the success of such strategies depends on the level of compliance (C) by the public. Given the choice, the public may evade (E) the restrictions and make the policy ineffective or comply (C) and render it effective. When choosing a strategy, the pay-off of the public depends on a balance of them perceived pay-off of compliance (C) against the pay-off of risking infection through evasion (E). Staying home has its economic cost while being infected has its cost. The public weigh the two and consider the one with lower cost. Thus, the effectiveness of each policy largely...
depends on the public’s willingness to comply. If this is not the case, then possible control of the virus without policy effectiveness implies herd immunity. Arbitrarily, the following equilibrium scenarios may be hypothesised:

**Scenario I:** In the first days of the epidemic, the governments knew little about the Covid-19. Both of them may not be willing to restrict early. However, if the governments take evasive actions (L) or respond lately, the social losses would be high.

**Scenario II:** Governments would consider political and economic factors, and previous experience in fighting the epidemic, by considering restricting (R). At this time, the probability of large-scale spread of Covid-19 is reduced. This equilibrium is attained after bearing losses from the prior-loss-bearing equilibrium at Scenario (I). This is to mean, Scenario (II) is most likely to be reached if the game is played repeatedly given that the public complies (C).

**Scenario III:** Governments may restrict (R) in all its best means but due to conditions of the restrictions which would not provide the public with a means of living, the public will evade (E) restrictions. The policy positions would be found to be increasing the spreading rate.

**Scenario IV:** Policy stances may not be influencing the rate of spreading at all but signs of control may be visible on the contagion side. Herd immunity may be the intuition behind this.

In order to model this, the paper follows Casini and Perron (2018) closely, by considering a linear regression with n breaks (or n + 1 regimes):

\[ Y_t = x_t'^β + w_t'θ_t + ε_t \quad t = T_{j-1} + 1, \ldots, T_j \quad \ldots \ldots \quad (1) \]

for \( j = 1, \ldots, n + 1 \), following Bai and Perron (1998). In this model, \( Y_t \) is the observed dependent variable; \( x_t(p \times 1) \) and \( w_t(p \times 1) \) are vectors of covariates; \( β \) and \( w_t(j = 1, \ldots, n + 1) \) are the corresponding vectors of coefficients; \( ε_t \) is the disturbance. The break dates \( T_{(1)}, \ldots, T_{(n)} \) are unknown (the convention that \( T_{0} = 0 \) and \( T_{n+1} = T \) is used). The aim is to estimate the regression coefficients and the break points when \( T \) observations on \( (Y_t, x_t, w_t) \) are available. This is a partial structural change model since the parameter vector \( β \) is not subject to shifts. When \( p = 0 \), a pure structural change model can be obtained. A partial structural change model can be beneficial in terms of obtaining more precise estimates and more powerful tests. The method of estimation is standard least-squares (OLS), which minimizes the overall sum of squared residuals (SSR):

\[ \sum_{i=1}^{n+1} \sum_{t=T_{(i-1)}+1}^{T_{(i)}} [Y_t - x_t'^β - w_t'θ_t]^2 \quad \ldots \ldots \ldots \quad (2) \]

Let: \( \hat{β}(T) \) and \( \hat{θ}(T) \) denote the estimates based on a partition \( (T_{(1)}, \ldots, T_{(n)}) \) denoted by \( (T) \). Substituting these in the objective function and denoting the resulting SSR as \( S_T(T_{(1)}, \ldots, T_{(n)}) \), the estimated break points are:

\[ (\hat{T}_{(1)}, \ldots, \hat{T}_{(n)}) = \text{arg min}_{T_{(1)}, \ldots, T_{(n)}} S_T(T_{(1)}, \ldots, T_{(n)}) \quad \ldots \ldots \ldots \quad (3) \]

with the minimization taken over a set of admissible partitions. The parameter estimates are those associated with the partition \( (\hat{T}) \), i.e., \( \hat{β} = \hat{β}(\hat{T}) \), \( \hat{θ} = \hat{θ}(\hat{T}) \). Since estimation is based on OLS, even if changes in the variance of \( ε_t \) are allowed, provided they occur at the same dates \( (T_{(1)}, \ldots, T_{(n)}) \), they are not exploited to increase the precision of the break date estimators unless a quasi-likelihood framework is adopted. Model (1) was estimated where the number of \( T \) was obtained and the confidents of the structural breaks were used to infer on the impact of phased policies in corresponding breaks.

Data on the Positive Rate (PR) and the Stringency Index (SYI) computed by our World in Data (OWID, 2021) using Covid-19 statistics submitted by the South African and Zimbabwean governments were used. The Stringency Index (SYI) is a composite measure based on nine response indicators which are: ‘school closures; workplace closures; cancellation of public events; restrictions on public gatherings; closures of public transport; stay-at-home requirements; public information campaigns; restrictions on internal movements; and international travel controls, rescaled to a value from 0 to 100 (100 = strictest)’ (OWID, 2021). The PR was modelled as the independent variable and the SYI as the dependent variable.

**RESULT AND DISCUSSION**

**Descriptive statistics**

The rate of positive cases is higher in South Africa than in Zimbabwe though the highest level of stringency are equal between the two countries. On average, Zimbabwe is found to be more stringent than South Africa.

**Table 2: Descriptive Statistics**

<table>
<thead>
<tr>
<th></th>
<th>South Africa</th>
<th>Zimbabwe</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR</td>
<td>0.1254</td>
<td>0.0704</td>
</tr>
<tr>
<td>Median</td>
<td>0.0935</td>
<td>0.0480</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.3260</td>
<td>0.2870</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.0150</td>
<td>0.0010</td>
</tr>
<tr>
<td>PR</td>
<td>61.324</td>
<td>70.897</td>
</tr>
<tr>
<td>Median</td>
<td>57.410</td>
<td>71.300</td>
</tr>
<tr>
<td>Maximum</td>
<td>87.960</td>
<td>87.960</td>
</tr>
<tr>
<td>Minimum</td>
<td>13.890</td>
<td>27.780</td>
</tr>
</tbody>
</table>
The researchers estimated the structural break model to determine the possible equilibria over a series of interventions. Data revealed five estimable structural breaks where each set of interventions represented by the stringency index can be evaluated. The two countries were implementing policies sequentially and symmetrically, where South Africa was arbitrarily the first player and Zimbabwe responding, ideally taking their best strategies. Thus the evolutionary equilibria created can be regarded as Nash. Results are presented in Table 4 below.
The study considered Covid-19 as a novel infectious disease that is spread through direct contact between individuals. Outbreak control measures implemented to reduce the contacts within the population can reduce the rate of positive cases. However, phases four and five were characterised by adverse intended outcomes. Policy interventions were increasing the rate of positive cases. In South Africa, it ranged from 0.0032 to 0.0044 for the respective phases while in Zimbabwe it was much lower at 0.0010 and 0.0018 for the two phases. In line with scenario (III), it can be inferred that the public had suffered enough costs of staying home and other stringent measures thus resorting to evasion as a strategy. Resultantly, the stringency policy stances failed in curbing the spreading of the virus.

The intercept statistic, measuring self-containment of the virus, had interesting results. It was negative in all cases except in the first phase for both countries and in the last phase for Zimbabwe. An evidence of an in-built heard immunity can be inferred. It is important to note that the statistic has been fairly decreasing throughout the phases for Zimbabwe but fluctuating for South Africa. This could be highly related to the different Covid-19 variants associated with the three waves of the virus mutations.

CONCLUSION

The study considered Covid-19 as a novel infectious disease that is spread through direct contact between individuals. Outbreak control measures implemented to reduce the contacts within the population can reduce the rate of positive cases.
the height of the peak, the speed at which the virus spreads, and the impact of the infection. In South Africa and Zimbabwe, different policies and strategies have been implemented, based on the experience and recommendations of WHO to control the spreading of Covid-19 as information was availed with time. An evolutionary game was modelled with a learning-aspect assumed component where players had an imitation tendency. The results showed evidence of a social learning path with phased interventions. This became a game with repeated plays. Convergence in policy stance by the two countries revealed a possible gain in the first phase but losses in the last two phases. The delayed intervention in the first phase had implicated losses. The research posited a high level of evasion by the public on stringent conditions by the governments as indicated by the results of the last two phases. Further, an evidence of natural herd immunity was noted between the two countries. It was recommended that future stringent policies should be public centred where governments attend to public needs whenever stringent conditions are applied. These include provision of a source of living and other needs which may force people to evade restrictions.

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