International Research Journal of Natural and Applied Sciences
ISSN: (2349-4077)
Impact Factor 5.46 Volume 8, Issue 04, April 2021
Website- www.aarf.asia, Email : editoraarf@gmail.com

ANALYSIS OF ECONOMIC BURDEN CAUSED BY INFLUENZA: INSURANCE BASED ACTUARIAL MODEL

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ABSTRACT

Influenza is a respiratory viral infection caused by influenza viruses. Since influenza cases are recorded annually around the world, it is essential to estimate the economic burden caused by this disease. This study estimates economic burden in an individual level which occurs due to medical and death expenditures. To estimate this economic burden caused by influenza, an insurance based actuarial model is used in this study. Data was obtained from Centers for Disease Control and Prevention web site and data contained weekly recorded influenza patients in United States. In the first stage of the study periodicity patterns of the data was analyzed using Fourier analysis and it was identified that there is a peak for influenza once a year. Using this result simulations were carried out year wise using Kermack-McKendrick model to study the behavior of the epidemic and to determine the values of the epidemic parameters. Finally the economic burden was estimated using the insurance based actuarial model and the variation of economic burden was analyzed with respect to removal rate and force of interest. A positive relationship was identified between economic burden and removal rate and the variation of economic burden with respect to force of interest was a function with a peak, reaching its maximum point between 0.04 and 0.05.

Keywords: Insurance based actuarial model, Fourier analysis, Kermack-McKendrick model, Removal rate, Force of interest

1. Introduction

Influenza is known as a highly transmissible and acute viral infection. There are four types of Influenza viruses: type A, B, C and D. Type A and B are known as human Influenza viruses and cause seasonal flu epidemics each year. Current subtypes of influenza A viruses found in people are influenza A (H1N1) and A (H3N2) viruses. Influenza C virus cause mild illness and do not cause epidemics. Type D Influenza mainly affect cattle and still not recorded for virus infected in humans (Centers for Disease Control and Prevention, 2019). The flu varies from mild to severe illnesses and even cause death resulting annually three to five million severe cases and nearly 290 000 to 650 000 respiratory deaths around the world(World Health Organization (WHO), 2014).

In 20th century three Influenza pandemics occurred. The 1918 influenza pandemic was the most severe pandemic occurred in recent history which was caused by an A(H1N1) virus. It was estimated that about one-third of the world's population became infected with this virus and at least 50 million deaths occurred worldwide. In 1957 a new influenza A(H2N2) virus appeared in East Asia causing the pandemic "Asian Flu" with globally estimated number of deaths of 1.1 million. The 1968 pandemic was caused by an influenza A (H3N2) virus and it was first noted in the United States in September 1968. The estimated number of deaths from this pandemic was one million worldwide. Recently another influenza pandemic occurred in year 2009.This was first noted in the United States and was caused by A(H1N1) virus. The globally estimated deaths of the pandemic were 201,200 respiratory deaths and with an additional 83,300 cardiovascular deaths. (Centers for Disease Control and Prevention, 2018)

Since Influenza has spread worldwide direct costs occur due to allocating money for drugs, vaccines, providing hospital facilities for patients and other medical costs. Further effects of the disease are deaths, loss of human hours and decrease in tourism arrivals. So, Influenza has resulted a catastrophe in health sector and as well as economic downturn. Therefore, it is very important to model the risk of this epidemic and to estimate the economic burden caused due to the disease.

The economic burden caused by a disease can be defined in two ways. They are individual level which estimates burden due to medical and death expenditures and public level which estimates the burden due to loss of human hours. The insurance based actuarial model used in this study estimates the economic burden in an individual level due to influenza and the burden is conceptually defined as the cost associated with an infected person which has to be borne by any susceptible.(Perera, 2017).

Many literatures can be found in modelling epidemics. (Nsoesie et al., 2012) analyzed individual and joint effects of parameters on the dynamics of simulated influenza epidemics using an individual based model. The global epidemic and mobility model was used to estimate the spread of 2014 west African Ebola outbreak by (Gomes et al., 2014). To determine the seasonal transmission potential and activity peaks of the novel influenza A(H1N1) a global structured metapopulation model was used by (Balcan et al., 2009) . In the study done by (Yoshizawa, 2016) have used Kermack-Mckendrick model, which has been used in this study.

Economic burden of influenza has been estimated in various studies using different methods. In the study done by (Mao et al., 2012) direct and indirect cost of Influenza were determined for each United States counties using kriging and spherical models. (Akazawa et al., 2003) estimated the number of workdays missed and average work loss due to influenza-like illness using Multivariate Regression Analysis. In the study done by (Meltzer et al., 1999) estimated the cost occurs due to number of illnesses and deaths of influenza using Monte Carlo mathematical simulation models. An insurance based actuarial model was introduced by (Perera, 2017) to estimate the economic burden of influenza. Also in this study this insurance based actuarial model is used to estimate the economic burden of influenza.

The objectives of this study are to identify the dynamics of the epidemic using Kermack-Mckendrick model, to estimate the economic burden and to analyze the behavior of economic burden with respect to parameters. This study will be important to policy makers, epidemiologists and to disease control strategies. Also we can use this model to predict the economic burden and since the economic burden is proportional to risk from the estimated economic burden we can determine the risk of influenza.

2. Materials and Methods

The theories and algorithms used to examine the periodicity of the data, to model the epidemic and to estimate and analyze the economic burden is explained in this section.

2.1 Data Collection

Data was obtained from 'Centers for Disease Control and Prevention' web site. Data consisted weekly reported influenza cases in United States (US) from year 2000 to year 2017. Since the population data was required to get the fraction of influenza patients, the US population was obtained from the World Bank reports.

2.2 Fourier Transform

The Fourier Transform (FT) is a mathematical function that takes a time-based pattern as input and determines the overall cycle offset, rotation speed and strength for every possible cycle in the given pattern. The FT is applied to waveforms which are basically a function of time, space or some other variable. The FT decomposes a waveform into a sinusoid and thus provides another way to represent a waveform.

FT of function $f(t)$ is defined as,

$$F(v) = \int_{-\infty}^{\infty} f(t) e^{-2\pi i v t} \, dt$$

Then inverse FT of $F(v)$ can be obtained by,

$$f(t) = \int_{-\infty}^{\infty} F(v) e^{2\pi i v t}\, dv$$

In the above equations, t stands for time and v stands for frequency.

2.3 Kermack-McKendrick Model

Kermack-McKendrick model (Yoshizawa, 2016) is a SIR model which is used in epidemic modelling. Let $S(t), I(t)$ and $R(t)$ denote the number of susceptible, infective and removals respectively at time t. Here removals are considered as dead, isolated, or immune individuals. Let N represents the total size of the population. Then $N = S(t) + I(t) + R(t)$ is assumed to be fixed for all $t \geq 0$. The system of ordinary differential equations due to Kermack and Mckendrick is expressed as follows.

$$\frac{dS(t)}{dt} = -\beta S(t) I(t) \quad (1)$$

$$\frac{dI(t)}{dt} = \beta S(t) I(t) - \gamma I(t) \quad (2)$$

$$\frac{dR(t)}{dt} = \gamma I(t) \quad (3)$$

These equations are analyzed under the initial conditions,

$S(0) = S_0$, $I(0) = I_0$ and $R(0) = 0$ with $S_0 + I_0 = N$

Here β indicates the infection rate and γ indicates the removal rate.

2.4 Insurance Based Actuarial/Probabilistic Model

In this model (Perera, 2017) susceptible are considered as the persons who make investment to cover future medical expenses and infective are considered as who gets benefit from the investment. Considering $S(t)$ and $I(t)$ as the probability of an individual being susceptible and infective respectively at time t,

Let,

$Expected\ (Actuarial)\ Present\ Value\ of\ T\ period\ unit\ benefit\ payment = E[B(T)]$

Then,

$$E[B(T)] = \int_0^T \exp(-\delta t)\, P(Individual\ being\ infective\ at\ time\ t)\, dt \quad (4)$$

$$E[B(T)] = \int_0^T \exp(-\delta t)\, I(t)\, dt \quad (5)$$

Let,

$Expected\ (Actuarial)\ Present\ Value\ of\ T\ period\ premium\ payment = E[P(T)]$

Then,

$$E[P(T)] = \int_0^T \exp(-\delta t)\, P(Individual\ being\ susceptible\ at\ time\ t)\, dt \quad (6)$$

$$E[P(T)] = \int_0^T \exp(-\delta t)\, S(t)\, dt \quad (7)$$

Here δ is considered as the force of interest.

Using the equivalence principle technique, the economic burden, π can be obtained as below.

$$\pi\ E\ [Present\ value\ of\ premium] = E\ [Present\ value\ of\ future\ benefit] \tag{8}$$

Therefore, π can be expressed as,

$$\pi(t) = \frac{E[B(T)]}{E[P(T)]} = \frac{\int_0^T \exp(-\delta t) I(t)\, dt}{\int_0^T \exp(-\delta t) S(t) dt} \tag{9}$$

2.6 Sensitivity Analysis

Sensitivity Analysis is used to determine how independent variable values will affect a particular dependent variable under a given set of assumptions. Usage of the analysis will depend on one or more input variables within the specific boundaries. This is also called as the what – if analysis.

3. Results and Discussion

The results obtained from this study are illustrated in this section. Further the results are mainly described under the topics: time series plot, Fourier analysis, simulations on Kermack-Mckendrick model, insurance based actuarial model and sensitivity analysis.

3.1 Time series plot

In the initial stage a time series plot was constructed to analyze how weekly recorded influenza cases vary with the time. Figure 1 illustrates the time series plot obtained from year 2000 to year 2017.

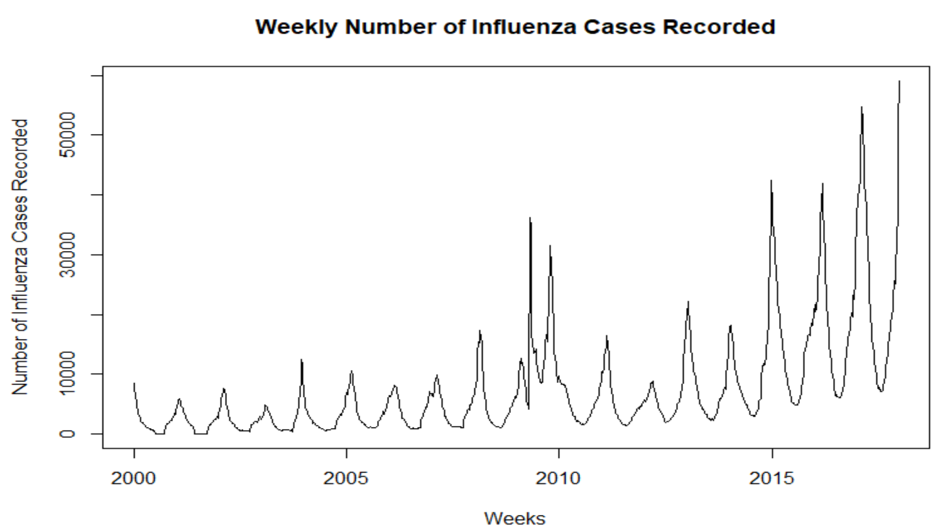

Figure 1: Weekly number of influenza cases recorded

From Figure 1 it can be observed that there is an upward trend. Further the time series plot implies that there is a periodic pattern in the data.

3.2 Fourier Analysis

A Fourier analysis was carried out to determine the periodicity of the data. First, the Fast Fourier Transform (FFT) was applied to the entire data set.

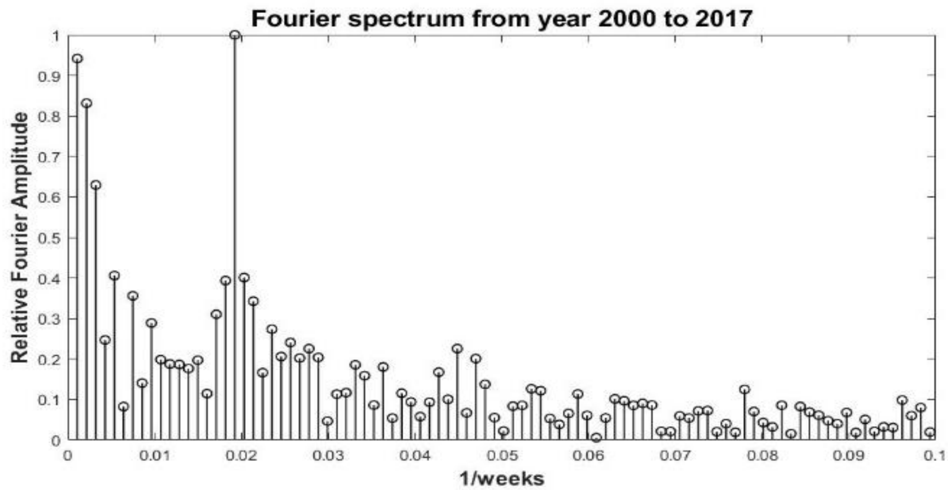

Figure 2: Fourier spectrum for weekly recorded Influenza cases from year 2000 to year 2017

From Figure 2 it can be observed that the highest Fourier amplitude appears from 0.01923 point. Since (1/0.0193) is approximately equal to 52, periodicity of recorded Influenza cases is 52 weeks. Therefore, we can conclude that there is a peak for influenza once a year.

Then FFT was applied for yearly data to observe periodic patterns for each year. Results indicated 52 weeks periodicity except for year 2009.

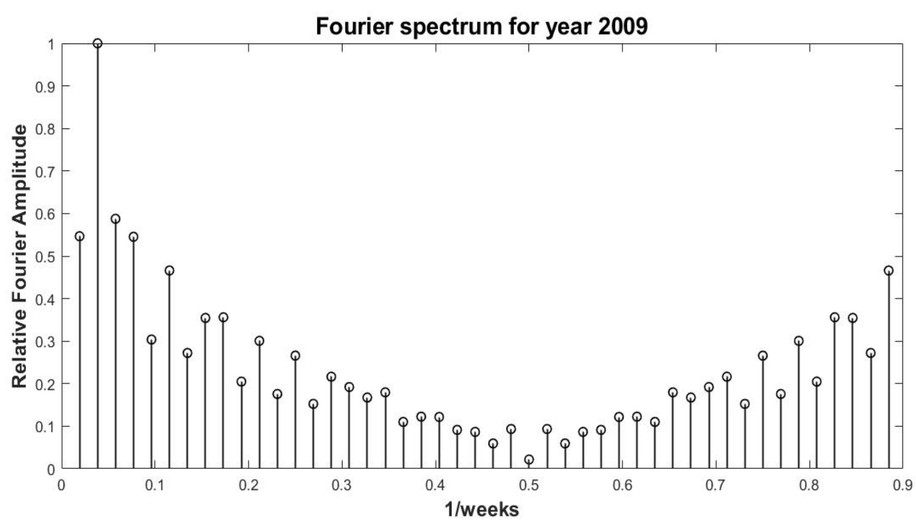

Figure 3: Fast Fourier transform spectrum for weekly recorded Influenza cases for year 2009

From figure 3 it can be observed that for year 2009 the highest amplitude appeared for the value 0.03486. Since (1/0.03486) is approximately equal to 28 weeks it was concluded that there are two peaks for year 2009.

Since the peak for recorded influenza data appeared in the beginning of the year, it was considered from the 30th week of one year to the 29th week of next year as an influenza year.

3.3 Kermack-McKendrick Model

Simulations were carried out using Kermack-McKendrick model to determine the behavior of susceptible, infective and removals with respect to time and epidemic parameters. The considered parameters were infection rate and removal rate.

For simulations, Equation (1), (2) and (3) in Kermack-Mckendrick model was used. And the infection rate and removal rate (Perera, 2017) were obtained as follows.

Infection rate for a given week was estimated from the equation,

$$a \times \{x(t-1) + \sin(2\pi t / Angular\ Frequency)\} \tag{10}$$

Here a is a constant and $x(t-1)$ denotes the fraction of infected population in the previous week. A sine function was used to model infection rate because data was distributed with a sinusoidal pattern. And t represents the given week. When proceeding with simulations the fraction of the infected population was estimated by dividing number of influenza patients by the population in US.

Removal rate was estimated from the equation

$$\frac{1}{Average\ Duration\ of\ the\ Infectious\ Period} \tag{11}$$

3.4 Insurance based Actuarial/Probabilistic Model

Expected present value of premium in Equation (7) was further simplified as follows.

$$E[P(T)] = \int_0^T \exp(-\delta t)\ S(t)\ dt$$

$$E[P(T)] = \int_0^T S(t)\ \frac{d\left(\frac{exp(-\delta t)}{-\delta}\right)}{dt}\ dt$$

$$E[P(T)] = -\frac{1}{\delta}[S(t)\exp(-\delta t)]_0^T + \frac{1}{\delta}\int_0^T \exp(-\delta t)\ \frac{dS(t)}{dt}\ dt$$

$$E[P(T)] = -\frac{1}{\delta}(S(T)\exp(-\delta T) - S(0)) + \frac{1}{\delta}\int_0^T \exp(-\delta t)\frac{dS(t)}{dt}\ dt$$

Since $\frac{dS(t)}{dt} = -\beta S(t)I(t)$ (From Equation 1)

By substituting the value for $\frac{dS(t)}{dt}$ by $-\beta S(t)I(t)$

$$E[P(T)] = \frac{1}{\delta}\left(S(0) - S(T)\exp(-\delta T)\right) + \frac{1}{\delta}\int_0^T \exp(-\delta t)\ \left(-\beta S(t)I(t)\right) dt$$

$$E[P(T)] = \frac{1}{\delta}\big(S(0) - S(T)\exp(-\delta T)\big) - \frac{1}{\delta}\int_0^T \exp(-\delta t)\ \big(\beta S(t)I(t)\big)\, dt$$

Since $\frac{dI(t)}{dt} \ = \beta S(t)I(t) - \gamma I(t)$ (From equation 2)

Substituting $\beta S(t)I(t) = \frac{dI(t)}{dt} + \gamma I(t)$ to the equation,

$$E[P(T)] = \frac{1}{\delta}\big(S(0) - S(T)\exp(-\delta T)\big) - \frac{1}{\delta}\int_0^T \exp(-\delta t)\ (\frac{dI(t)}{dt} + \gamma I(t))\ dt$$

$$E[P(T)] = \frac{1}{\delta}\big(S(0) - S(T)\exp(-\delta T)\big) - \frac{1}{\delta}\int_0^T \exp(-\delta t)\frac{dI(t)}{dt}dt - \frac{\gamma}{\delta}\int_0^T \exp(-\delta t)\, I(t)dt$$

$$E[P(T)] = \frac{1}{\delta}\big(S(0) - S(T)\exp(-\delta T)\big) - \frac{1}{\delta}\{[\exp(-\delta t)\, I(t)]_0^T - \int_0^T I(t)\frac{d\exp(-\delta t)}{dt}dt\}$$

$$-\frac{\gamma}{\delta}\int_0^T \exp(-\delta t)\, I(t)dt$$

$$E[P(T)] = \frac{1}{\delta}\big(S(0) - S(T)\exp(-\delta T)\big) - \frac{1}{\delta}[\exp(-\delta T)\, I(T) - I(0)] - \int_0^T I(t)\exp(-\delta t)\, dt$$

$$-\frac{\gamma}{\delta}\int_0^T \exp(-\delta t)\, I(t)dt$$

$$E[P(T)] = \frac{1}{\delta}\big(S(0) - S(T)\exp(-\delta T)\big) + \frac{1}{\delta}[I(0) - \exp(-\delta T)\, I(T)] - \int_0^T I(t)\exp(-\delta t)\, dt$$

$$-\frac{\gamma}{\delta}\int_0^T \exp(-\delta t)\, I(t)dt$$

$$E[P(T)] = \frac{1}{\delta}(I(0) + S(0) - \exp(-\delta T)(S(T) + I(T)) - (1 + \frac{\gamma}{\delta})\int_0^T \exp(-\delta t)\, I(t)dt$$

Since $I(0) + S(0) = 1$

$$E[P(T)] = \frac{1}{\delta}(1 - \exp(-\delta T)(S(T) + I(T)) - (1 + \frac{\gamma}{\delta})\int_0^T \exp(-\delta t)\, I(t)dt$$

Then the obtained equation for economic burden is,

$$\pi = \frac{\int_0^T \exp(-\delta t)\, I(t)\, dt}{\frac{1}{\delta}(1 - \exp(-\delta T)(S(T) + I(T)) - (1 + \frac{\gamma}{\delta})\int_0^T \exp(-\delta t) I(t) dt} \tag{12}$$

Since this equation is applied for a year $T = 52$ weeks and exp $(-\delta T)(S(T) + I(T))$ closes to zero because $\exp(-\delta T) = 0.074$ and $S(T) + I(T) < 1$
So by removing exp $(-\delta T)(S(T) + I(T))$, the equation simplifies as follows.

$$\pi \approx \frac{\int_0^T \exp(-\delta t)\, I(t)\, dt}{\frac{1}{\delta} - (1+\frac{\gamma}{\delta}) \int_0^T \exp(-\delta t)\, I(t)\, dt} \tag{13}$$

Using above equation economic burden for each year was estimated.

Since discrete data were available for number of infected cases, a piecewise continuous approximation of this continuous function was obtained as follows.

$$\tilde{I}(t) = \begin{cases} I_k; & k-1 < t \leq k \\ 0; & otherwise \end{cases}$$

$$E[B(T)] = \int_0^T \exp\,(-\delta t)\, I(t)\, dt$$

$$E[B(T)] \approx \int_0^T \exp\,(-\delta t)\, \tilde{I}(t)\ \ dt$$

$$E[B(T)] \approx \sum_{k=1}^{T} \left(\frac{\exp\big(-\delta(k-1)\big) - \exp\,(-\delta k)}{\delta} \right) I_k$$

Now π can be expressed as,

$$\pi \approx \frac{\sum_{k=1}^{T} \big(\exp\big(-\delta(k-1)\big) - \exp\,(-\delta k)\big) I_k}{1 - \left(1+\frac{\gamma}{\delta}\right) \sum_{k=1}^{T} \big(\exp\big(-\delta(k-1)\big) - \exp\,(-\delta k)\big) I_k} \tag{14}$$

3.5 Sensitivity Analysis

Since the economic burden depends on force of interest and removal rate, sensitivity analysis was carried out to analyze the behavior of economic burden with respect to these parameters. And the analysis was done year wise.

The range of force of interest was taken from 0.01 to 0.1.
And the range of removal rate was taken from $\frac{1}{4}$ to 1.

When proceeding with simulations the system was stable when the infectious period is one week or more than one week. So the upper bound of removal rate was taken as one. And assuming that the maximum duration that an infected person can spread the disease to another person is 4 weeks the lower bound of removal rate was taken as $\frac{1}{4}$.

The variation of economic burden was analyzed with respect to force of interest and removal rate from year 2000-2001 to year 2016-2017. Below the results are described for year 2000-2001.

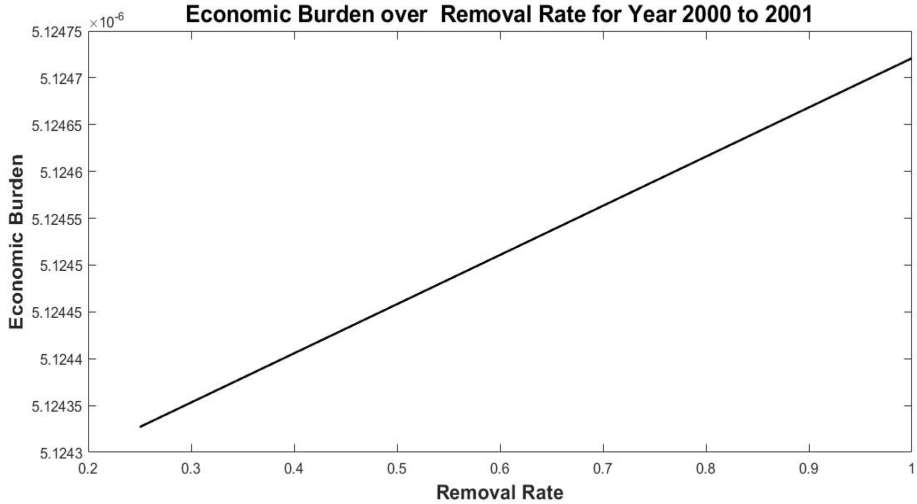

Figure 4: Variation of Economic Burden with respect to Removal Rate for year 2000 to 2001. Parameters: Force of Interest = 0.05

Figure 4 describes the variation of economic burden for year 2000 to 2001 with respect to removal rate with force of interest 0.05. When removal rate varies from 0.25 to 1, there can be observed a positive relationship between economic burden and removal rate.

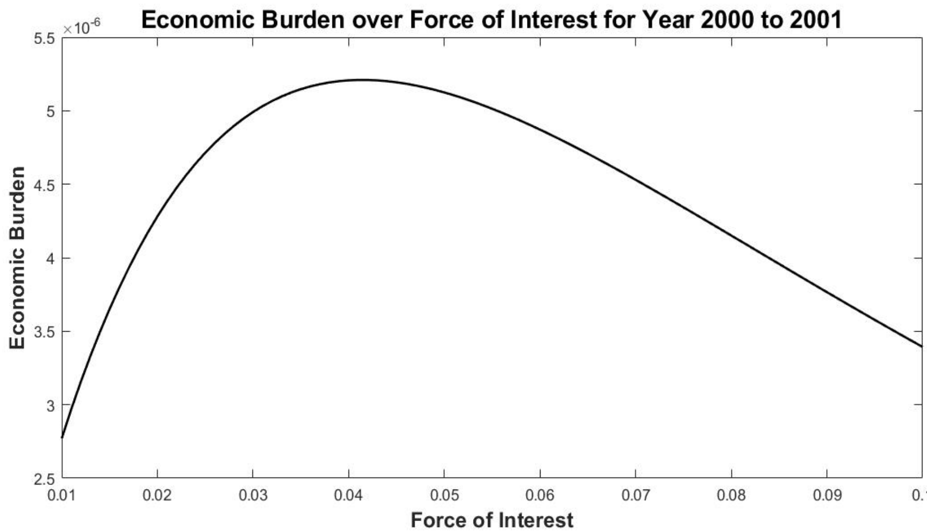

Figure 5: Variation of Economic Burden with respect to Force of Interest for year 2000 to 2001. Parameters: Removal rate = 0.55

Figure 5 describes the variation of economic burden for year 2000 to 2001 with respect to force of interest with removal rate 0.55. When force of interest varies from 0.01 to 0.1, it can be observed that the economic burden with respect to force of interest is a function with a peak and achieves its maximum point at 0.041.

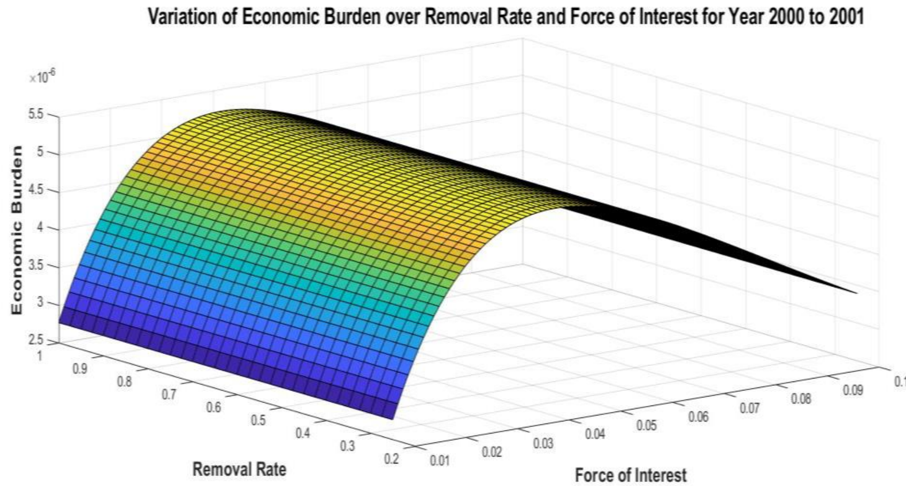

Figure 6: Variation of Economic Burden with respect to Force of Interest and Removal Rate for year 2000 to 2001

Figure 6 describes the variation of economic burden with respect to both removal rate and force of interest for year 2000 to 2001.

4. Conclusion

Since influenza has been widely spread around the world, it is important to estimate the economic burden caused by this flu. The insurance based actuarial model used in this study estimates the economic burden in an individual level which occurs due to medical and death expenditures.

In this study first fast Fourier transform was applied to examine the periodicity of the data. The results gave that the periodicity for each year is equal to 52 weeks except for year 2009. For year 2009 the periodicity was equal to 28 weeks. Using this result next simulations were carried out to observe the behavior of the epidemic and as well as to determine the range of removal rate. Since the economic burden depended on removal rate and interest rate, the behavior of economic burden with respect to these parameters was analyzed. The analysis was done year wise and the range of the removal rate was considered from $1/4$ to 1, while the range of interest rate was taken from 0.01 to 0.1.

When considering the results from year 2000-2001 to 2016-2017, for variation of economic burden with respect to removal rate it was observed that there is a positive relationship. In the analysis of variation of economic burden with respect to force of interest the economic burden is a function with a peak, achieving its highest point between 0.04 and 0.05.

Since no accurately recorded data were available in Sri Lanka, influenza data of United States has been used in this research. This was a main limitation in the study. Further in simulations, though the peak was achieved the actual shape of the real data was not achieved. The simulation model would be more accurate if climatological data such as rainfall and temperature are considered. In this study Kermack-Mckendrick model (SIR model) was used for epidemic modelling. Also the Insurance based Actuarial model can be developed for other epidemic models. Then variation of economic burden can be further analysed for other epidemic parameters.

5. References

Akazawa, M., Sindelar, J. L., & Paltiel, A. D. (2003). Economic costs of influenza-related work absenteeism. *Value in Health*, *6*(2), 107–115. https://doi.org/10.1046/j.1524-4733.2003.00209.x

Balcan, D., Hu, H., Goncalves, B., Bajardi, P., Poletto, C., Ramasco, J. J., Paolotti, D., Perra, N., Tizzoni, M., Broeck, W. Van Den, Colizza, V., & Vespignani, A. (2009). *Seasonal transmission potential and activity peaks of the new influenza A (H1N1): a Monte Carlo likelihood analysis based on human mobility*. *12*, 1–12. https://doi.org/10.1186/1741-7015-7-45

CDC, C. for D. C. and P. (2019). Types of Influenza Viruses | CDC. In *Cdc.Gov*.

Centers for Disease Control and Prevention. (2018). Past Pandemics | Pandemic Influenza (Flu) | CDC. In *Centers for Disease Control and Prevention* (p. 1). https://www.cdc.gov/flu/pandemic-resources/basics/past-pandemics.html

Gomes, M. F. C., Pastore y Piontti, A., Rossi, L., Chao, D., Longini, I., Halloran, M. E., & Vespignani, A. (2014). Assessing the International Spreading Risk Associated with the 2014 West African Ebola Outbreak. In *PLoS Currents*. https://doi.org/10.1371/currents.outbreaks.cd818f63d40e24aef769dda7df9e0da5

Mao, L., Yang, Y., Qiu, Y., & Yang, Y. (2012). Annual economic impacts of seasonal influenza on US counties: Spatial heterogeneity and patterns. In *International Journal of Health Geographics* (Vol. 11). https://doi.org/10.1186/1476-072X-11-16

Meltzer, M. I., Cox, N. J., & Fukuda, K. (1999). The economic impact of pandemic influenza in the United States: Priorities for intervention. *Emerging Infectious Diseases*, *5*(5), 659–671. https://doi.org/10.3201/eid0505.990507

Nsoesie, E. O., Beckman, R. J., & Marathe, M. V. (2012). Sensitivity Analysis of an Individual-Based Model for Simulation of Influenza Epidemics. *PLoS ONE*, *7*(10). https://doi.org/10.1371/journal.pone.0045414

Perera, S. S. N. (2017). *Analysis of Economic Burden of Seasonal Influenza : An Actuarial Based Conceptual Model*. *2017*.

World Health Organization (WHO). (2014). Influenza (Seasonal). In *Bulletin of the World Health Organization*.

Yoshizawa, Y. (2016). *Risk estimation model on epidemic outbreaks for an insurer*.