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Euroscore Overestimated Cardiac Surgery Related Mortality: Comparing Euroscore Model and Bayesian Approach using New Generalized Probabilistic Model with New Form of Prior Information

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Abstract

Objectives: *An attempt is made to suggest an alternative approach using Bayesian analysis in predicting the mortality during cardiac surgery. The risk index predicted through Bayesian approach is compared with the traditional approach EuroSCORE Model for known data sets available in the internet [see [4]].*

Methods: *The overall mortality related to cardiac surgery was traced from 2002 to 2012.The data was extracted from the official blue book website of the Society for Cardiothoracic Surgery in Great Britain & Ireland. The cohort included patients who underwent cardiac surgery in NHS hospital and other private hospitals in U.K. During each year, the true mortality, predicted mortality by EuroSCORE, and estimated mortality through Bayesian approach were compared.*

Results: *Overall mortality rates derived from EuroSCORE Model were much higher (more than double) of true reported mortality rate for the period 2006 to 2012, and almost 60% higher for the period 2003 to 2005, than the true mortality reported by the Society for Cardiothoracic Surgery in Great Britain & Ireland in its official website. While the Bayesian approach predicted mortality rates estimates that are more consistent, significantly lower than the one estimated by EuroSCORE, and much closer to the reported true mortality.*

Conclusions: *Mortality rate post-surgery is considered a quality metric to hospitals. Bayesian approach provides greater advantage over EuroSCORE in predicting mortality post cardiac surgery. Both are noticed to overestimate the real surgical risk, being less with the Bayesians. Bayesian approach is an alternative predictor to estimate mortality post cardiac surgery and should be verified by further research.*

Keywords : *Bayesian Analysis, Cardiac Surgery Activity, Data Analysis, EuroSCORE Model, Markov Chain Monte Carlo, Mortality Rate, Informative Prior.*

I. INTRODUCTION

Surgical mortality is considered a quality metric for hospitals. Elevated risk might not be accepted by many patients and hence their treatment can be compromised. Moreover, insurance services expected to raise their premium in case the anticipated surgical mortality is high. Consistent mortality prediction that can mimic the true mortality is crucial. Various Therapeutic decisions can be balanced with the most appropriate risk benefit ratio. The present study is an attempt to validate a risk predictor post cardiac surgery model and compare it to the EuroSCORE. This study might have a particular interest to cardiologists, and cardiac surgeons.[1] Au et al (2007) compared the models, EuroSCORE [[2] Nashef et al (1999)] and Parsonnet model [[3] Parsonnet et al (1989)] to predict the mortality rate, using adult patients data with cardiac surgery activities. For the comparison they used the data on the number of patients 1247 (observed mortality rate 2.9%) undergone coronary artery bypass graft (CABG) and the patients 1407 (observed mortality rate 4.8%) undergone CABG at the Grantham Hospital, Hong Kong from November 1999 to July 2005. They found that EuroSCORE model performed much better than Parsonnet model in predicting mortality. However, they observed a tendency for both models to over predict mortality rate.

II. METHODOLOGY

In this paper, we considered Bayesian approach, using a new informative prior we call it Informative Unit interval prior [*infuitp*(θ,π)] in the interval (0,1). By applying Markov Chain Monte Carlo simulation, to obtain the posterior summaries required for an uncertain parameter for the data of the observed mortality rates after the cardiac surgery activity. This data analysis may be of some interest to demographers, cardiologists, actuaries, biostatisticians and health policy makers. The Society for Cardiothoracic Surgery in Great Britain & Ireland in its official website [see [4]], allows access to information about the clinical condition of the patient, type of cardiac surgery, and post-operative outcomes including mortality. Recently, we came across the data related to observed mortality rate and predicted mortality rate using EuroSCORE model when a cardiac surgery conducted in an NHS hospital and a number of the private hospitals during the financial year 2003 to 2012. EuroSCORE model is commonly used to predict mortality rate. Such model required the data on patient related factors as well as cardiac related factors. It has been adopted worldwide, becoming the most widely used risk index for cardiac surgery.

Using Bayesian approach, we compared the posterior estimates (with actual deaths) and with ones predicted using EuroSCORE model. This comparison at micro level can be used as a measure of the quality of hospital performance. This study may give some insight, how the Bayesian method for making inference about an uncertain parameter *p* on the basis of prior knowledge that behaves as proposed *infuitp*(θ,π).

The parameter *p* of success in a number of *n* trials, with *x* number of successes such that *x~genbin*(*n,p,a,b,c*) a generalized binomial probabilistic model [equ (2.1)], along with the three data sets used (Table 1).The Bayesian approach by using new prior information, the informative prior *infuitp*(θ,π) [eqn (VII.1)] and the Bayesian summary in Tables 2, 3, and 4 are presented. The comparison of the posterior estimates obtained by using the proposed prior, are made in section 4, using Tables 2, 3, and 4 and figures1-3. Lastly, in Appendix we have given the pdf of new *infuitp*(θ,π), the cumulative distribution function along with the r-th moment, for further research and for the researchers who want to verify the results for more data sets obtained in different regions of the world.

III. THE MORTALITY RATES AFTER CARDIAC SURGERY AND THE PROBABILITY MODEL

The parameter of interest is the probability *p* of success in *n* number of trials, which can result in success or failure. The estimate, if there is a fixed number of trials, with *x* number of successes, such that *x~genbin*(*n,p,a,b,c*) a generalized binomial probabilistic model of index *x* and parameters *p, a, b, c*. Considering the three data sets in Table 1, which represent the number of operations and the mortality rates from the period 2003 to 2012. The years given in the three data sets represent a financial year. For example 2011 represents 1st April 2011 – 31st March 2012. It is worth to mention that though it is yearly data, yet it is not time series data. The three data sets in Table 1 were analyzed using Openbugs$^{@}$ computer software. Therefore, if we let x_t and n_t be the number of deaths, and the number of cardiac surgery performed in respective year *t*, this problem will be modeled as a binary response variable with true failure probabilities p_t. Thus x_t can follow *genbin*(p_t,n_t,a_t,b_t,c_t) a generalized binomial probabilistic model, where $x_t=0,1,\ldots,n_t$, $t=1,..,10$, that is (II.1)

$$f(x_t|p_t,a_t,b_t,c_t) = \binom{n_t}{x_t} p_t^{a_t x_t}\left(1-(1-p_t^{c_t})^{b_t}\right)^{n_t}\left[\frac{1}{1-(1-p_t^{c_t})^{b_t}}-p_t^{a_t}\right]^{n_t-x_t}$$

, $a_t > 0$, $b_t > 0$, $c_t \geq 0$.

We should emphasize that when $a_t=1$, $b_t=1$, and $c_t=0$, equation (II.1) is reduced to conventional binomial distribution [i.e., *genbin*$(p_t,n_t,1,1,0) \equiv bin(p_t,n_t)$].

The Bayesian approach, using prior information about the parameter *p*, to construct a new process before collecting and analyzing the data and updating the previous knowledge by using Bayes' theorem is well established in the literature. To obtain the Bayesian summary estimates we use a hierarchical model, because of its versatility [5]. Hence, for the present three data sets, we assume that the true failure probabilities for each year [see Table 1] having informative prior distribution for the p_t's, namely *infuitp*(θ_t,π_t),$t=1,..,10$. A realistic model for the surgical data is to suggest the hierarchical models, which is implemented as follows:

(a) At the first stage we assume a prior belief that follows *infuitp*(θ_t,π_t) for the true failure probabilities p_t for each hospital *t*.

(b) At the second stage, we assume the following prior specification for the hyperparameters θ_t and π_t, θ_t ~gamma(ϑ,Λ), and π_t ~gamma(ϑ,Λ) independent.

(c) At the third stage, we assume the following prior specification for the hyper-hyperparameters where ϑ~exponential(T), Λ~exponential(T), $T=0.1$.

A Markov Chain Monte Carlo (MCMC) Gibbs sampling approach implemented in using OpenBugs$^{@}$ computer software is capable to analyze the estimates of surgical mortality in each year *t*. A burn in of 1000 updates followed by a further 11000 updates give estimates of $p_{t,}$ for each year t=1,…,10.

Table 1. The Mortality Rates from 2003-2012

Year	All cardiac surgery		Isolated first time CABG (overall cohort)		Isolated first time CABG (elective patients)	
	Number of Operations	**Mortality rates (%)**	**Number of Operations**	**Mortality rates (%)**	**Number of Operations**	**Mortality rates (%)**
2003	36374	3.74	22879	1.98	16393	1.25
2004	37453	3.62	23135	1.86	16443	1.22
2005	35922	3.56	20987	1.68	14412	1.00
2006	36654	3.58	20951	1.74	14132	1.19
2007	39202	3.12	22376	1.40	15071	0.76
2008	39239	3.21	21121	1.57	14024	1.04
2009	36321	3.14	19137	1.57	12370	1.03
2010	34737	3.25	17986	1.60	11097	0.95
2011	34959	2.97	17754	1.44	10654	0.70
2012	34174	2.98	16791	1.40	9760	0.89

IV. RESULTS

Table 2, for informative prior *infuitp*(θ,π), represent the estimates of surgical mortality for each year, along with standard deviation, median and MC error. From Table 2, it can be noticed that there is a marginal shift to the right in the estimates posterior median from the true mortality rate for all cardiac surgery for all years (Table 1). Almost similar type of observations can be seen for the rest of the years from 2003 to 2012. From table 2, it is evident that the prediction of surgical mortality rate by using proposed *infutip* prior with hierarchical model for each year is more close to the true mortality rates for this data set. When the EuroSCORE model is used, it over predict mortality rate by almost 100% for most of the years. The over prediction is almost more than 150% from the true values for the years 2011 and 2012.

Table 3, represent the estimates of surgical mortality isolated first time CABG (overall cohort), for each year, along with standard deviation, median and MC error for informative prior *infuitp*. From Table 3, it is clearly seen that there is a marginal shift to the right in the estimates posterior median from the true mortality rate for all data set isolated first time CABG (overall cohort), for all years (Table 1). Almost consistent observations can be seen for the rest of the years from 2003 to 2012. As shown in table 3, it can be noted that the prediction of surgical mortality rate isolated among first time CABG patients (overall cohort) calculated by proposed *infutip* prior with hierarchical model for each year is more close to the true mortality rates for this data set. When the EuroSCORE model is employed, the estimated mortality almost doubled the true values for the years 2003 to 2006, and tripled the actual rate in years 2007 to 2012.

Table 4, represents the estimates of surgical mortality isolated first time CABG (elective patients) for each year, along with standard deviation, median and MC error for informative prior *infuitp*(θ,π). Table 4 has shown the similar marginal shift to the right in the estimates posterior median from the true mortality rate for data set isolated first time CABG (elective patients), for all years (Table 1). A similar type of observations can be seen for the rest of the years from 2003 to 2012. From table 4, it can be noted that the prediction of surgical mortality rate isolated first time CABG (elective patients) by using proposed *infutip* prior with hierarchical model for each year is more close to the true mortality rates for this data set. When the EuroSCORE model is used, it over predict mortality rate by almost twice from the true values for most of the year. The over prediction is almost more than three times from the true values from the years 2007 to 2012.

As depicted in table 5, across the data sets for the years 2002 to 2012, the Bayesian predicted mortality is significantly lower than calculated by EuroSCORE(P-value<.05).

Table 2. Bayesian Summary of all Cardiac Surgical Mortality for Each Year with Informative Prior *infuitp*

Year	Mean	SD	MC error	2.5%	Median	97.5%
2003	0.05065	0.03497	5.349E-4	0.004972	0.04274	0.1329
2004	0.04924	0.03409	5.619E-4	0.004722	0.04145	0.1301
2005	0.04912	0.0348	5.007E-4	0.004459	0.04140	0.1322
2006	0.04912	0.03549	5.834E-4	0.004622	0.04111	0.1334
2007	0.04435	0.03296	5.712E-4	0.003591	0.03631	0.1249
2008	0.04431	0.03277	5.020E-4	0.003622	0.03648	0.1248
2009	0.04339	0.03338	6.270E-4	0.002856	0.03553	0.1250
2010	0.04359	0.03417	6.548E-4	0.002836	0.03488	0.1272
2011	0.04307	0.03399	5.519E-4	0.002358	0.03414	0.1284
2012	0.04377	0.03468	6.54E-4	0.002663	0.03520	0.1290

Table 3. Bayesian Summary of Cardiac Surgical Mortality Isolated First Time CABG (overall cohort) for Each Year with Informative Prior *infuitp*

Year	Mean	SD	MC error	2.5%	Median	97.5%
2003	0.03862	0.03876	7.846E-4	4.09E-4	0.02544	0.1399
2004	0.03811	0.03835	6.822E-4	3.986E-4	0.02534	0.1384
2005	0.0381	0.03983	8.446E-4	2.813E-4	0.02421	0.1442
2006	0.03872	0.04055	8.954E-4	2.196E-4	0.02429	0.1471
2007	0.03459	0.03785	7.874E-4	1.596E-4	0.02048	0.1357
2008	0.03688	0.03922	8.28E-4	2.512E-4	0.02286	0.1404
2009	0.03667	0.04073	8.018E-4	1.417E-4	0.0214	0.147
2010	0.03931	0.04243	9.885E-4	1.963E-4	0.02331	0.1517
2011	0.03878	0.04212	9.769E-4	1.186E-4	0.02318	0.1499
2012	0.03908	0.04385	0.001001	9.558E-5	0.02227	0.1552

Table 4. Bayesian Summary of Cardiac Surgical Mortality Isolated First Time CABG (Elective Patients) For Each Year With Informative Prior *Infuitp*

Year	Mean	SD	MC error	2.5%	Median	97.5%
2003	0.03557	0.04060	9.097E-4	5.149E-5	0.01968	0.1434
2004	0.03621	0.04150	8.761E-4	4.926E-5	0.01989	0.1435
2005	0.03428	0.04212	0.001070	3.091E-6	0.01640	0.1468
2006	0.03861	0.04461	0.001143	3.383E-5	0.02080	0.1544
2007	0.03331	0.04158	0.001058	9.176E-6	0.01549	0.1455
2008	0.03789	0.04407	0.001059	2.406E-5	0.01989	0.1528
2009	0.03859	0.04611	0.001190	1.631E-5	0.01900	0.1586
2010	0.04208	0.04665	0.001046	2.990E-5	0.02384	0.1589
2011	0.03958	0.04846	0.001521	3.980E-6	0.01789	0.1621
2012	0.04401	0.04955	0.001485	2.309E-5	0.02448	0.1680

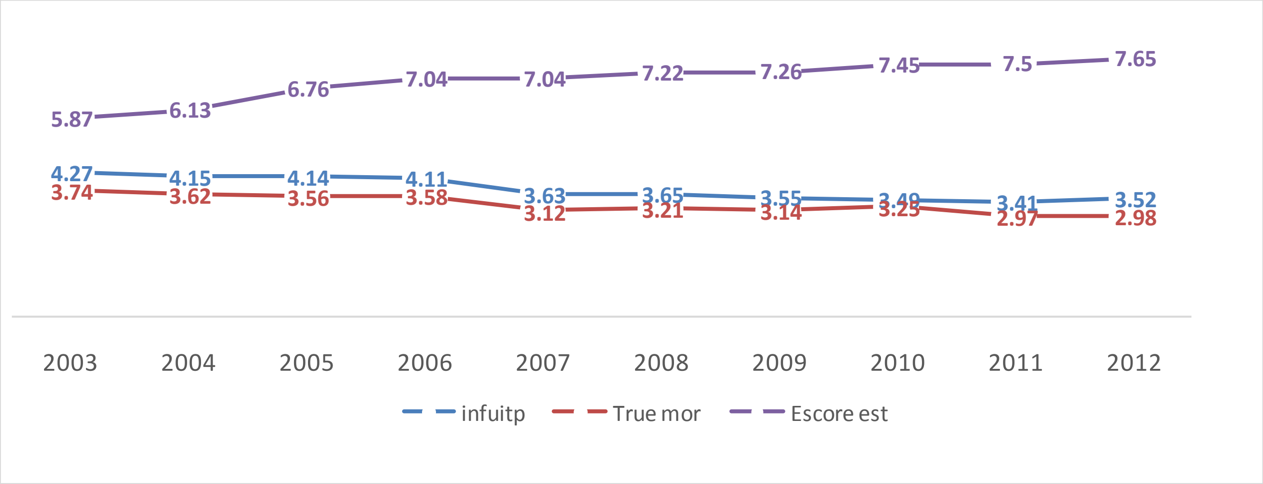


Fig 1. Chart Of Summary of all Cardiac Surgical Mortality Prediction in (%) for Each Year Compared With Mortality Rates

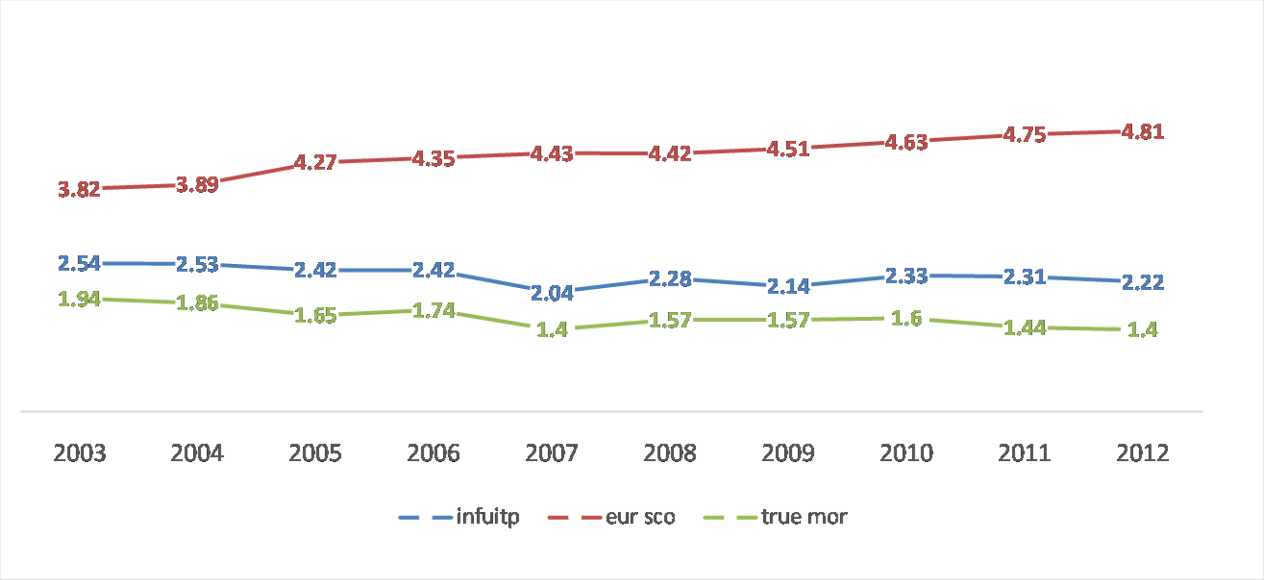
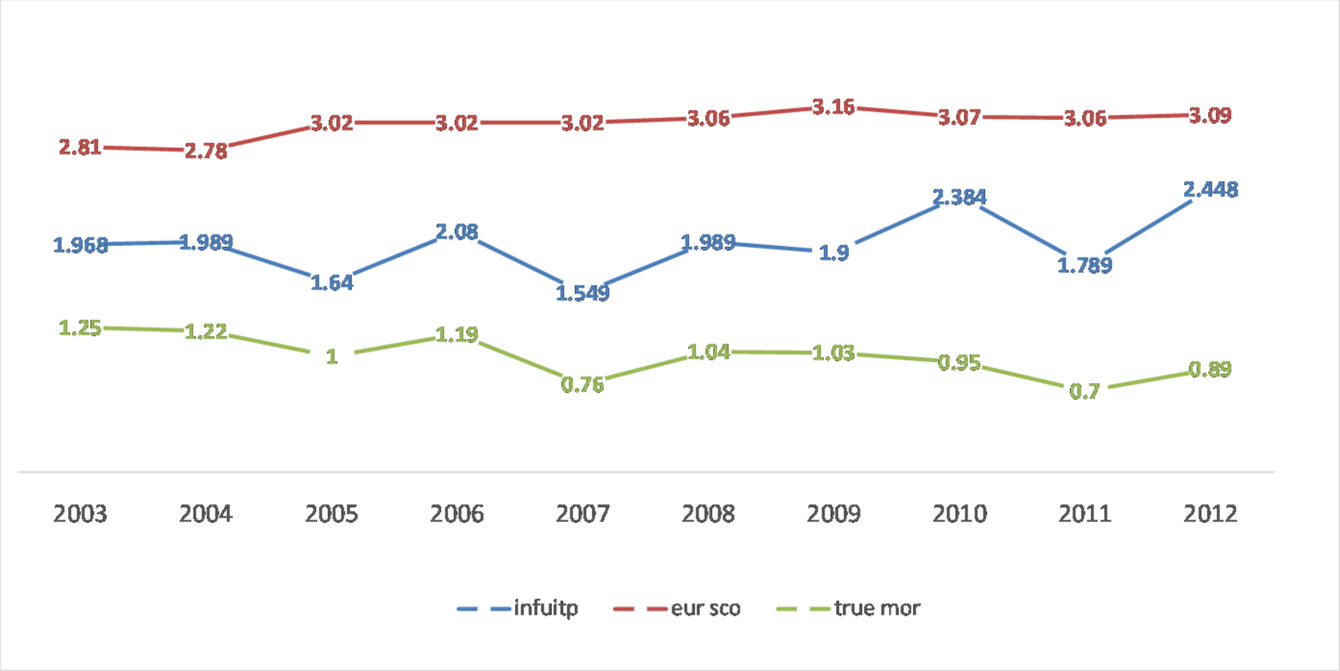


Fig 2. Chart of Summary of Cardiac Surgical Mortality Prediction in (%) Isolated First Time CABG (Overall Cohort) for Each Year Compared with Mortality Rates

Fig 3. Chart Of Summary Of Cardiac Surgical Mortality Prediction In (%) Isolated First Time CABG (Elective Patients) For Each Year Compared With Mortality Rate



V. DISCUSSION

Here an attempt is made to propose an alternative approach to predict mortality post cardiac surgery other than EuroSCORE. As being evident in the literature the latter tended to overestimate such mortality [9]. Figures 1, 2 and 3 represent the summary of true surgical mortality in (%), prediction in (%) for each year, by Euroscore model and by Bayesian approach by using proposed *infutip* prior with hierarchical model for each year . For these particular data sets prior *infuitp* with hierarchical model performed the best, and the posterior medians are consistent with the observed values than the predicted value using EuroSCORE model. It is evident that by employing the Bayesian analysis, the posterior estimates using priors *infuitp* with hierarchical resulted in more consistent estimates than predicted values using EuroSCORE model, and closer to observed values for all the years. It can be seen that EuroSCORE model had consistently overestimated the mortality for the years 2003 to 2012, which is far from concordance with true values. While Bayesian analysis the posterior estimates using prior *infuitp* with hierarchical model had more coherent results which true values have. Interestingly, the prediction is quiet close to the true values for all three data sets. Potential errors are anticipated when applying the EuroScore. After the original EuroSCORE was developed, the use of off-pump CABG gained considerable popularity, especially between 1997 and 2000. Advances in medical treatment, thrombolytic therapy, and percutaneous interventions in recent years have also altered the profile of patients referred for cardiac surgery [10]. To maintain accurate prediction, statistical models should have periodic recalibration that can parallel the metamorphosis of the disease profile and therapeutic advances.

VI. CONCLUSION

EuroSCORE often overestimated cardiac surgery related mortality. Bayesian approach seems a valuable alternative that worth further research. At the same time caution to be practiced when deciding the individual candidacy prior to cardiac surgery. Cardiac team approach rather than decision based merely on EuroSCORE is strongly encouraged.

VII. BAYESIAN APPROACH BY USING NEW PRIOR INFORMATION

First, let us introduce the following new prior, the pdf of the new informative unit interval type prior *infuitp*(θ, π) of a random variable X, with parameters $\theta > 0$, $\pi \geq 0$ (or $\theta \geq 0$, $\pi > 0$), is defined in equation (VII.1) as follows:

(VII.1)

$$f(x) = \frac{\sqrt{2}(\theta+\pi)x^{\theta+\pi-1}}{\left(x^{\theta\pi}+1\right)^{3/2}}\left[\left(1-\frac{\theta\pi}{2(\theta+\pi)}\right)x^{\theta\pi}+1\right], \quad x \in (0,1)$$

The (cdf) cumulative distribution function of (VII.1) is $F(x) = \frac{\sqrt{2}x^{\theta+\pi}}{\sqrt{x^{\theta\pi}+1}}$.

From the pdf (VII.1), and F(x) function, it can be seen that they do not have special functions in the equations. It can be noted that for $\theta = 0, \pi = 1$, the distribution reduces to uniform and straight line and hence add to versatility, and can be used as non-informative prior in case where expert's information either not true or doubtful or the equal probabilities are assigned to all possibilities. The distribution is also, unimodal and hence convenient to handle.

The *r*th moment about origin of *infuitp*(θ, π) is given in eq (VII.2)

(V[[.2) $\mu_r' =$

$$\frac{1}{\sqrt{2}}\left[\frac{1}{r+\theta+\pi+\theta\pi}\left((2\theta+2\pi-\theta\pi)F'_{\frac{r+\theta+\pi}{\theta\pi}+1}\right)+\frac{1}{r+\theta+\pi}\left((2\theta+2\pi)F'_{\frac{r+\theta+\pi}{\theta\pi}}\right)\right]$$

Where, $F_v' = F\left(\left[\frac{3}{2}, v\right]; [1+v]; [-1]\right)$, and F is the generalized hypergeometric series. [see [8] Andrews, Chapter 9, p 365], and is defined by:

(VII.3)

$$F([n_1, n_2, \ldots, n_s]; [d_1, d_2, \ldots, d_t]: z) = \sum_{k=0}^{\infty} \frac{\left(\prod_{i=0}^{s} \frac{\Gamma(n_i+k)}{\Gamma(n_i)}\right) z^k}{\left(\prod_{i=0}^{t} \frac{\Gamma(d_i+k)}{\Gamma(d_i)}\right) k!}$$

Unlike the pdf eq (VII.1) and F(x) of *infuitp*(θ, π), the r-th moments do have special functions in the eq (VII.2). However, by using eq (VII.2) we can compute the mean and the variance and/or the r-th moments which are not difficult to obtain. [10] Feng, Li wrote an R function to calculate the generalized hypergeometric function for real numbers. With minor changes we can use his function to compute eq (VII.2).

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