Impact case study template (REF3b)

Centile and growth curves estimation (London Metropolitan University)

1. Summary of the impact (indicative maximum 100 words)

The methodology for growth curve estimation developed by Rigby and Stasinopoulos (2004,2006) has been used worldwide. The World Health Organisation used the methodology and the related software exclusively for developing child growth standards, WHO (2006, 2007, 2009). The Global Lung Function Initiative (GLFI), (www.lungfunction.org, Stanojevic *et al*. 2008, Cole *et al*. 2009,) use it for providing a unified worldwide approach to lung function in growth and ageing. The methodology is now the gold standard for developing growth curves.

2. Underpinning research (indicative maximum 500 words)

The most popular method for growth curve estimation was the LMS method developed by Cole and Green (1992). Rigby and Stasinopoulos (2004, 2005, 2006) extended the LMS method (which allows for location, scale and skewness but not for kurtosis in the data), by introducing the 4-parameter Box-Cox power exponential (BCPE) and the Box-Cox t (BCT) distributions and called the resulting centile and quantile estimation methods LMSP and LMST, respectively. The BCCG (equivalent to the LMS method), BCPE and BCT distributions are part of the GAMLSS general framework of models. The GAMLSS methodology for growth curves also generalised the LMS method by allowing multiple explanatory variables and factors in the model for each of the four parameters of the BCPE or BCT distributions something which was found useful in the GLFI.
The interest of the two researchers in growth curve methodology started around 2000. In September 2002 Dr Rigby and Prof. Stasinopoulos were contacted by the Department of Nutrition for Health and Development of the World Health Organisation, expressing an interest in the then little known GAMLSS models as a potential method for the construction of growth curves. This resulted in a close collaboration, which led to improvements in the GAMLSS software with the inclusion of several diagnostic techniques appropriate for comparing and evaluating the fitted growth curves. In the summer of 2003 the decision was taken by WHO that the LMSP method using the BCPE distribution was the most appropriate method for the construction of the standard growth curves for the merged data collected from six representative countries of the world. The arguments for choosing the GAMLSS methodology for constructing the growth curves, as opposed to at least 30 other competing methodologies, were published by Borghi *et al.* (2006). The WHO subsequently published the actual child growth standards curves in three volumes, WHO (2006, 2007, 2009).
Another example of worldwide application of the GAMLSS methodology is the Global Lung Function Initiative (GLFI). The GLFI aim is to set a unified worldwide approach to lung function in growth and ageing. The GAMLSS methodology was used to provide equations for obtaining the lung function centile 'z-score' given values of age, height, ethnic group and gender.
These are two major applications of the GAMLSS methodology in growth curve fitting, although the method is also now used widely for the construction of growth curves.

Both Dr Rigby and Prof. Stasinopoulos have been researching continuously at London Metropolitan University (University of North London before 2001) for more than twenty years.

3. References to the research (indicative maximum of six references)

2004 Rigby, R. A. & Stasinopoulos, D. M. Smooth centile curves for skew and kurtotic data modelled using the Box-Cox power exponential distribution. *Statistics in Medicine*, 23, 3053-3076

2005 Rigby R. A. and Stasinopoulos M.D. Generalised additive models for location scale and shape, (with discussion), Appl. Statist., 54, part 3, pp 507-554.

2006 Rigby R. A. and Stasinopoulos M.D. (2006) Using the Box-Cox t distribution in GAMLS modelling of skewness and kurtosis. Statistical Modelling, 6, pp 209-229.

2006 Borghi E, de Onis M, Garza C, Van den Broeck J, Frongillo EA, Grummer-Strawn L, Van Buuren S, Pan H, Molinari L, Martorell R, Onyango AW, Martines JC, Construction of the World Health Organization child growth standards: selection of methods for attained growth curves *Statistics in Medicine* 2006;25(2):247-65.

(the first three papers were submitted in that last RAF)

4. Details of the impact (indicative maximum 750 words)

The GAMLSS growth curve methodology has improved and extended the previous major existing methodology of the LMS method. The researchers also provide free appropriate software for fitting the models and most importantly checking their adequacy. This allows the user to find the most appropriate model for their data.

The impact of any statistical methodological contribution, such as the GAMLSS growth curve methodology, can only be measured by its usefulness in practical applications and the impact those applications have to the wider community. In what it follows we will argue that this is the case with GAMLSS methodology. Firstly, we will consider the impact that the WHO Growth Reference Study has and will have upon world health.

The following quote from their website explains the aims of their study:
"The WHO Multicentre Growth Reference Study (MGRS) was undertaken between 1997 and 2003 to generate new growth curves for assessing the growth and development of infants and young children around the world. The MGRS collected primary growth data and related information from approximately 8500 children from widely different ethnic backgrounds and cultural settings (Brazil, Ghana, India, Norway, Oman and the USA). The new growth curves are expected to provide a single international standard that represents the best description of physiological growth for all children from birth to five years of age and to establish the breastfed infant as the normative model for growth and development."

Upon the completion of the analysis WHO published three books, WHO (2006, 2007, 2009), which are available from their website http://www.who.int/childgrowth/standards/en/. The impact of the release of Growth Reference Study curves is explained by the article "Worldwide implementation of the WHO Child Growth Standards" of de Onis *et al. (*2012) from which the following quote is taken "By April 2011, 125 countries had adopted the WHO standards, another twenty-five were considering their adoption and thirty had not adopted them. Preference for local references was the main reason for non-adoption." The article also provided a map to show which countries adopted

the WHO standards curves.

The important point to make here is that results, from applying the GAMLSS methodology, are used and will be used for the next decades in a majority of countries of the world for checking the health and the wellbeing of children.

A further major application of the methodology is its use by the Global Lung Function Initiative. The initiative uses GAMLSS methodology to provide equations for obtaining the lung function centile 'z-score' given values of age, height, ethnic group and gender, Quanjer et al. (2012a). The equations have been adopted by a variety of commercial companies, as can be seen in the page 'Manufacturers' in the www.lungfunction.org page.

5. Sources to corroborate the impact (indicative maximum of 10 references)

The following three volumes provide evidence for the use of the GAMLSS methodology and software in the creation of the child growth standards by WHO:

WHO Child Growth Standards: Methods and development: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age. (2006) Geneva: World Health Organization

WHO Child Growth Standards: Methods and development: Head circumference-for-age, arm circumference-for-age, triceps skinfold-for-age and subscapular skinfold-for-age. (2007) Geneva: World Health Organization,

WHO Child Growth Standards: Methods and development (2009) Growth velocity based on weight, length and head circumference. Geneva: World Health Organization.

The following articles support the use of the GAMLSS methodology and software by the Global Lung Function Initiative:

Cole, T. J., Stanojevic, S., Stocks, J., Coats, A. L., Hankinson, J. L. and Wade, A. M. (2009) Age- and size related reference ranges: A case study of spirometry through childhood and adulthood. *Statistics in Medicine*,**28**, 880-898.

Stanojevic, S., Wade, A.M., Stocks, J., Hankinson, J.L., Allan, L., Coates, A.L., Pan, H., Rosenthal, M., Corey, M., Lebecque, B., and Cole, T.J. (2008) Reference ranges for spirometry across all ages: a new approach. *American Journal of Respiratory and Critical Care Medicine*, **177**, 253-260.

Quanjer, P.H., Stanojevic, S., Cole, T.J., Baur, X., Hall, G.L., Culver, B.H., Enright, P.L., Hankinson, J.L., Ip, I.M.S.M. Zheng, J., Stocks, J. and the ERS Global Lung Function Initiative (2012a Multi-ethnic reference values for spirometry for the 3-95-yr age range: the global lung function 2012 equations. *European Respiratory Journal*, **40**, 1324-1343.

Quanjer, P.H., Stanojevic, S., Stocks, J. and Cole, T.J. (2012b) GAMLSS in action. Available from www.lungfunction.org