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BY EMAIL TO: Chris.Pattas@aer.gov.au

Dear Mr Pattas,

SUBMISSION TO THE AER'S DRAFT RATE OF RETURN GUIDELINE (AUGUST 2013)

Methods for determining the cost of debt at a point in time

In the explanatory statement that was released with its draft rate of return guideline, the AER intimated that there were difficulties involved in estimating the cost of debt for a benchmark corporate bond with a ten-year term to maturity[1]. The AER alluded to potential problems that were intrinsic to the task of extrapolating the Bloomberg fair value curve from a 7-year term to a 10 year term to maturity[2]. As a result of the non-availability of a third party data source to provide a comprehensive assessment of the 10-year cost of debt, the AER decided to reduce the term for the cost of debt to 7-years[3].

United Energy and Multinet Gas believe that an appropriate method for estimating the cost of debt at a particular point in time is via the use of term structure models, such as the Nelson-Siegel formulation. Depending upon market conditions, the use of term structure models might provide a worthy alternative or complement to methods that are based on the extrapolation of the Bloomberg BBB fair value curve.

The estimation of Nelson-Siegel curves offers an attractive approach which, if properly undertaken, is

[1] AER (2013), Better Regulation, Explanatory Statement, Draft rate of return guideline, Australian Energy Regulator, August 2013; section 7.3.1, page 99.

[2] Ibid; section 7.3.3, page 108.

[3] Ibid; section 7.3.3, page 109.

capable of harnessing a wide range of market information about the yields on corporate bonds, as traded in the secondary market. The Nelson-Siegel equation is also theoretically well specified. As explained by the authors, the discount rate function is obtained by integrating a forward rate function which is itself the solution to a second-order differential equation with real and unequal roots[4].

ESQUANT Statistical Consulting was engaged by United Energy and Multinet Gas to assess the statistical case for the use of yield curve methods. ESQUANT made use of a database of corporate bonds which was assembled by the Competition Economists Group (CEG). The measurement period for the analysis was 20 business days in February 2013. ESQUANT investigated the suitability of the yield curve approach for determining the benchmark cost of debt for a 10 year corporate bond[5].

The model developed by Nelson and Siegel (1987) is parsimonious but has the ability to generate the shapes typically associated with yield curves. The model is widely used by central banks either in its original form or in the modified form that was provided by Svensson (1994)[6]. An important contribution of the analysis by ESQUANT has been the estimation of zero-coupon yield curves or spot rate curves that belong to the family of Nelson-Siegel curves. Subsequently, ESQUANT used those estimates to generate estimates of par yield curves. Schaefer (1977) shows how one can uncover the term structure of par yields from the term structure of spot rates[7].

There is considerable merit in par yield curves because these are obtained after adjusting the observations on bond yields for differences in the size and timing of coupon payments.

The approach that we use is to search for a term structure of spot rates that will minimise an objective function that is a weighted average of the squared differences between the actual prices of a range of bonds, and the prices of those bonds that the term structure of spot rates indicates should prevail. The actual bond prices that we use are the so-called ‘dirty’ prices. The dirty price of a bond is the price that one must pay to buy the bond. The ‘clean’ price is, in contrast, the dirty price less an amount representing ‘accrued’ interest. The price of a bond that the term structure of spot rates indicates should prevail is simply the cash flows that the bond will deliver discounted using the term structure.

Long-term bonds exhibit greater sensitivity to interest rates than short-term bonds. Therefore, minimising an objective function that is an equally weighted average of the squared differences between the actual prices of a range of bonds and their predicted prices will tend to fit long-term bond prices rather than short-term bond prices. An appropriate adjustment to make, therefore, was to apply a weighting method to the bond observations in the sample, and the scheme which is supported in the

4 Nelson, C.R. and A.F. Siegel, *Parsimonious Modeling of Yield Curves*, The Journal of Business, Volume 60, Issue 4 (October 1987); page 475.

5 ESQUANT (2013), *The development of yield curves, zero coupon yields, and par value yields for corporate bonds*, A report prepared for United Energy and Multinet Gas in response to the AER’s draft rate of return guideline, 17th October 2013.

6 See, for example, the discussion in: Bank for International Settlements, Zero-coupon yield curves: Technical documentation, Monetary and Economic Department, October 2005.

Svensson, L. (1994), “Estimating and Interpreting Forward Interest Rates: Sweden 1992-1994”, Technical Report 4871, National Bureau of Economic Research, Inc.

7 Schaefer, S.M. (1977), “The Problem with Redemption Yields”, Financial Analysts Journal, July-August 1977, pages 59-67.

literature is a function of the reciprocal of Macaulay duration. The latter is a measure of risk and computes the average maturity of a bond using the present values of its cash flows as weights. The apportioning scheme recorded the inverse duration of each bond as a function of the sum of the inverse durations of all bonds in the particular sub-sample[8].

ESQUANT also investigated the use of a non-linear mixed effects model as a means of sensibly combining the daily observations on bond yields over an averaging period. The mixed effects method controls for the idiosyncratic, structural features of a particular bond and also makes provision for serial correlation between the daily observations on bond yields. Therefore, the model can properly take into account the relationship between term to maturity and yield for a representative, average bond[9].

The application of a trailing average method for measuring the return on debt

The AER has made provision for the use of a trailing average method to determine the return on debt. The trailing average calculation is to be applied to the overall cost of debt (rather than to components such as the swap rate or the debt risk premium). The inputs into the calculation would be estimates of the yield on a benchmark corporate bond at particular points in time. The AER has indicated that there would be annual updating of the components of the weighted average return on debt formula[10]. However, the AER has spurned the use of yield curves, claiming that such a method would be unnecessarily complex[11]. The AER hasn't provided details about the aspects of the task which the regulator believes that it would be unable to perform.

United Energy and Multinet Gas consider that empirically determined yield curves have an important role to play, and that the investment of effort that is required is entirely justified by the materiality of the issues at stake. The derivation of the rate of return is an integral part of the revenue and price-setting process. The Companies believe that regulated businesses should participate fully in the development of yield curves.

New issue premium on primary bond issues

The submission by the Energy Networks Association[12] refers to the new issue premium that borrowers are obliged to pay when raising debt via corporate bond issuance. The yields on debt in primary issue markets are generally higher than the yields on debt in secondary markets, with the gap between the two described by practitioners as the new issue concession or new issue premium (NIP). The AER estimates the cost of debt for a 10-year tenor benchmark corporate bond with reference to secondary market data on bond yields. The AER therefore does not provide compensation for the margin over secondary spreads that must be paid to execute a new benchmark transaction.

[8] ESQUANT (2013), *The development of yield curves, zero coupon yields, and par value yields for corporate bonds*, A report prepared for United Energy and Multinet Gas in response to the AER's draft rate of return guideline, 17th October 2013; section 5.

[9] Ibid; section 4.

[10] AER (2013), Better Regulation, Explanatory Statement, Draft rate of return guideline, Australian Energy Regulator, August 2013; section 6.3.5, page 89.

[11] Ibid; section 7.3.1, page 99.

[12] ENA (2013), Response to the Draft Rate of Return Guideline of the Australian Energy Regulator; section 5.5.2, page 76.

The NIP arises in part because secondary market transactions are typically for smaller volumes than primary market transactions, which means that investors demand a premium relative to secondary trading levels in order to absorb the additional volume requirement. The NIP is related to market determined factors such as the size and tenor of the specific primary transaction, the bond spread relative to a risk-free rate benchmark, the trend in the bond spread, the tenor of the bond, and swap market volatility. Other determinants include the overall volume of primary issue debt currently in the market, and expectations for supply going forward. However, as is explained in the expert report prepared by Ronn and Goldberg, the occurrence of the new issue premium is also driven by market imperfections and transactions costs[13]. The new issue premium can be measured or estimated using empirical techniques.

A significant proportion of Australian companies access debt markets overseas, including in the USA. Australian corporations are known to raise finance in markets which include European wholesale, the Canadian market, United States Private Placement (USPP), US high yield, US registered, and the US 144A market. Ronn and Goldberg cite Bloomberg data which indicates that international bond issuance by Australian corporates was equal to $21 billion in the first quarter of 2013[14]. Other information compiled by the National Australia Bank suggests that, over the year to 23rd September 2013, Australian corporates raised A$15 billion of finance in the US 144A market, A$12 billion through private placements (USPP), and A$5 billion in the US high yield market[15].

These substantial borrowings mean that overseas data cannot simply be disregarded. Economic advisers, such as the Competition Economists Group, make use of information about bonds issued overseas in their assessments of the cost of debt. The database of corporate bonds which was used in the empirical analyses undertaken separately by CEG and by ESQUANT contained data on foreign currency bonds that had been issued by entities which were otherwise domiciled in Australia. The yields on bonds denominated in foreign currencies were swapped into Australian dollar yields using input data from the cross-currency swaps function that is available through the Bloomberg information service.

The estimate, derived by Ronn and Goldberg, of the ratio of the new issue premium to the spread on corporate bonds, is relevant at the present time. Ronn and Goldberg examined US$ bonds issued by Australian companies that were recorded on the United States TRACE system[16]. The authors measured the new issue premium on those bonds using a method that they had applied in a research study that had given rise to a published academic article[17]. Note that TRACE provided a high quality data source. The authors estimated that, for the particular sub-sample of Australian bonds, the ratio of the new issue premium to the bond spread over US Treasury yields was 10.3%. The result of 10.3% was evaluated as the arithmetic mean of values of the ratio measured across a sample of 32 bonds. The authors had found that the average value of the (NIP/Spread) ratio was 10.4% when measured across the entire

[13] Ronn, E.I. and R.S. Goldberg, Research into the New Issue Premium, and the Applicability of that Research to the Australian Bond Market, a submission prepared for United Energy and Multinet Gas in response to the draft rate of return guidelines of the Australian Energy Regulator, October 2013; section 5.1, page 22.

[14] Ibid; section 1.1, page 4.

[15] As reported in the AFR lift-out, Debt Funding, Australian Financial Review, Thursday 26th September 2013.

[16] Trade Reporting and Compliance Engine, a mandatory reporting scheme for over the counter, secondary market transactions in eligible fixed income securities.

[17] Goldberg R.S., and E.I. Ronn, Quantifying and Explaining the New-Issue Premium in the Post-Glass-Steagall Corporate Bond Market, Journal of Fixed Income, 2013, Volume 23, No. 1, pages 43-55.

database of approximately 1,500 bonds. Ronn and Goldberg determined that their NIP estimate of 10.3% of the bond spread would also be applicable to Australia because of similarities in institutional arrangements, and the partial integration of financial markets[18].

Return on debt: weighting schemes

United Energy and Multinet Gas are investigating the merits of adopting a trailing average approach to the determination of the return on debt. The AER's assessment that equal and invariant weights should be used in the calculation of a weighted average cost of debt under the trailing average approach is not supported by comprehensive analysis[19]. The Companies consider that the use of fixed weights over time (or an equally weighted average) may be inappropriate in certain circumstances, such as in those cases in which a business is experiencing marked growth in its regulatory asset base. The AER should be cautious about adopting immutable positions on the mechanics of trailing average computations in the absence of more rigorous work having been undertaken. Regulated businesses should be presented with an opportunity to prepare arguments for the use of time-varying weighting schemes. Businesses may be able to devise weighting methods that make use of information pertinent to a benchmark efficient entity, and thereby overcome potential problems associated with the use of firm specific data.

Final comment

I urge you or your staff to make contact with me, by telephone on (03) 8846 9854, if you have any queries about the submission.

Yours sincerely,

Jeremy Rothfield
Network Regulation and Compliance Manager

[18] Ronn, E.I. and R.S. Goldberg, Research into the New Issue Premium, and the Applicability of that Research to the Australian Bond Market, a submission prepared for United Energy and Multinet Gas in response to the draft rate of return guidelines of the Australian Energy Regulator, October 2013; section 5.3, page 25.

[19] AER (2013), Better Regulation, Explanatory Statement, Draft rate of return guideline, Australian Energy Regulator, August 2013; section 6.3.6, page 89.

ESQUANT
Statistical Consulting

The development of yield curves, zero coupon yields, and par value yields for corporate bonds.

A report prepared for United Energy and Multinet Gas in response to the AER's draft rate of return guideline.

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Competition Economists' Group

October 17, 2013

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1 Executive Summary

In early 2013, the Energy Networks Association (ENA) commissioned the Competition Economists Group (CEG) to assess indicators of the Debt Risk Premium for a representative corporate bond, with a 10-year term to maturity, and a BBB+ credit rating from Standard & Poor's. The tenor and credit rating were chosen to align with the current benchmark used by the Australian Energy Regulator (AER). CEG prepared a report (CEG, 2013a) which was lodged with the AER. A finding of the report was that when curve fitting techniques are applied to a broad selection of bond yield observations, then the results at a 10-year term to maturity are comparable to those obtained from an extrapolated Bloomberg BBB fair value curve. CEG (2013a) reported that an estimate of the debt risk premium, for a benchmark corporate bond with a 10-year term to maturity, and a BBB+ credit rating, was 2.98%. Note that CEG also released an addendum report (CEG, 2013b).

United Energy and Multinet Gas have approached ESQUANT Statistical Consulting with a request for independent advice on the suitability of the use of yield curves as a functional method for estimating the cost of debt.

We have been asked to conduct a review of the empirical work presented in the CEG reports so as to determine whether the methods applied to estimate the yield curves were reasonable and defensible. In our review we have re-estimated the yield curves using a different software package and algorithms, and have given standard errors for the estimated Debt Risk Premiums.

We acknowledge that we have read, understood and complied with the Federal Court of Australia's Practice Note CM 7, Expert Witnesses in Proceedings in the Federal Court of Australia.

Review of CEG methods (section 3 of this report).

CEG estimated the Nelson-Siegel model

$$\begin{aligned}\text{Yield}(t, \text{rank}) &= \beta_{1,\text{rank}} + (\beta_2 + \beta_3)\frac{1 - \exp(-t/\beta_0)}{t/\beta_0} - \beta_3 \exp(-t/\beta_0) \\ &= \beta_1 + (\beta_2 + \beta_3)\frac{1 - \exp(-t/\beta_0)}{t/\beta_0} - \beta_3 \exp(-t/\beta_0) + \beta_4\text{A-} + \beta_5\text{BBB}\end{aligned}$$

where t is the remaining term to maturity of the bond; $\beta_0 \ldots \beta_5$ are parameters to be estimated; and A- and BBB are dummy variables for A- and BBB bonds respectively. The model was fitted to 32 different groups of bonds, with each of the 32 groups categorised on the basis of the following variables: The ratings class of the bonds within the group, the currency in which the bond was issued, whether or not bonds with optionality features were permitted, the data source used (either Bloomberg, UBS rate sheets, or both sources), and the country of domicile of the issuer. The model was run using Excel Solver, and the fitted equation was then employed to calculate the debt risk premiums at 7 and 10 years.

In our review, we have re-estimated the yield curves for the four groups of bonds which were regarded by CEG as being most important. The four groups are highlighted in Table 4A of CEG (2013b), and make use of the broadest bond samples. The defining characteristics of the groups are shown in Table 1 of this report.

The database of corporate bonds used by CEG was supplied to ESQUANT. All of the bonds contained within this file had credit ratings which would be classed as investment grade. The data on the attributes of the bonds was originally sourced from Bloomberg and UBS.

There is a close correspondence between the results that we have obtained, and those reported by CEG. In order to ascertain the precision of the results, there is a need to calculate standard errors for the parameter estimates, and for the estimates of the debt risk premium, *per se*. CEG estimated equations by drawing upon the individual, daily observations for the month of February 2013. In the work that was undertaken initially by ESQUANT, we used an arithmetic average of the daily observations over the reference period.

The Nelson-Siegel equation is a non-linear formulation. However, if one of the parameters (β_0) is held constant, then the equation effectively becomes linear in the other parameters. Standard errors from a non-linear regression rely on an assumption that the non-linear mean function can be approximated locally by a linear function of the parameters. We applied the profile t method (see, for example, Bates and Watts, 1988) to identify whether a linear approximation would be appropriate, and we were able to ascertain that a linear approximation would work well for all parameters except β_0. Accordingly, β_0 was re-parameterised by defining a new parameter, β_6, as the logarithm of β_0, and it should be noted that the re-parameterisation was designed not to change the model but to improve the estimation of it.

The re-parameterised Nelson-Siegel equation was applied to the averaged series for the datasets Data1, Data2, Data3, and Data4, the characteristics of which are shown in Table 1. Two methods of estimation were applied using R-software, R `optim` and R `nls`. Both methods provide strong assurance of finding an optimal solution (a global minimum) and also deliver unbiased results.

The overall cost of debt obtained by applying the R `nls` function to the broadest sample of bonds, represented by dataset Data3, was estimated to be 6.475% for a benchmark corporate bond with a 10-year term to maturity. The average value of the yields on 10-year Commonwealth Government Securities, (CGS), was 3.515% over the reference period (February 2013). Hence, the debt risk premium was worked out to be 2.96%.

The standard error corresponding to the DRP estimate of 2.96% was assessed to be 0.09% (as reported in Table 6). The low value of the standard error indicated that the debt risk permium evaluated for a 10-year term to maturity is highly statistically significant.

Again, using the largest dataset, Data3, the DRP for a 7-year benchmark corporate bond was calculated to be 2.76%, with a standard error of 0.1%, when the optimisation method applied was based on R `nls`. The increment to the DRP from 7 years to 10 years, was calculated to be 6.78 basis points per annum (bppa), with a low standard error of 1.49 bppa.

Similar results were obtained for the other data sub-samples, Data1, Data2 and Data4.

Refinements of CEG methods: (section 4 of this report).

There were a number of extensions to the methods used by CEG.

Robust analysis (section 4.1)

The regression residuals from the preliminary estimations of Nelson-Siegel curves were examined. A QQ plot presents the residuals, which are plotted on the y-axis, according to a 'quantile' distribution. Although the regression residuals were generally concentrated along a single trajectory, there was some evidence of the presence of a couple of outlying observations in the data, and so robust regression methods were employed. Robust regression makes use of MLE-like estimators (Venables and Ripley, 2008) and serves to moderate the impact of outiers. The R-estimation package, `nlrob`, was used in conjunction with the re-parameterised Nelson-Siegel model and the four datasets, Data1 to Data4. The results for the debt risk premium are shown in Table 7. For Data3, the DRP at 10 years was found to be 2.85%, with a standard error of 0.09%. The increment to the DRP, from 7 years to 10 years, was calculated to be 6.43 bppa with a standard error of 1.45 bppa.

Analysis of daily results (section 4.2)

The daily observations of yields, measured over a reference period for a large number of bonds, essentially give rise to a form of non-linear panel data. An appropriate way to analyse the daily results is to apply a non-linear mixed effects model, with random effects for the long-term parameter for each bond, and auto-correlation from day-to-day for the yields for each bond.

An advantage of using a mixed model specification is that it becomes possible to take full account of the fixed effect of the influence of term to maturity on the average yield for bonds of a particular tenor. Hence, the focus is taken away from the yields of individual bonds. In addition, any criticisms about the practice of using an arithmetic average of the daily yield results in Nelson-Siegel equations can be circumvented.

Daily plots of the estimated debt risk premiums (Figure 9 and Figure 10) suggested that the regression diagnostics from the mixed effects model were satisfactory. For the Data3 sub sample, the estimated DRP was 2.99% for a 10 year tenor bond, with a standard error of 0.09%. The estimate of the change in the DRP from a 7 year to a 10 year term to maturity was found to be 7.13 bppa, with a standard error of 1.44 bppa.

Are common parameters justified? (section 4.3)

The general practice adopted by CEG, when fitting Nelson-Siegel curves, has been to pool bonds with different credit ratings and to assume that most of the equation parameters are common across the ratings classes (see, for instance, CEG, 2013c). However, CEG has also used separate dummy variables for bonds rated A- and BBB (flat), respectively. In effect, a separate long maturity term applies to A- bonds and to BBB (flat) bonds. The parameter β_1 is the long maturity term for bonds with a credit rating of BBB+.

In the notation used in this report, the parameters β_0, β_2 and β_3 are assumed to be common to bonds of all credit ratings, as is the parameter β_6, which was obtained from a re-parameterisation. The assumption that the aforementioned parameters take on the same value for each of the three classes of bonds can be regarded as a form of restriction.

ESQUANT examined whether the restriction of common parameter values was valid by creating additional parameters that were linked to the main parameters, but which could deviate in value for bonds from different credit rating bands. The models based on varying parameters were plotted alongside the models which constrained some of the parameter values. An interesting observation was that although the fitted curves corresponding to different credit ratings sometimes took on different shapes, depending upon the dataset that was used, there were no instances in which the curves intersected.

A simple hypothesis test was undertaken to investigate whether the restriction of common parameters could be justified. The test was carried out by comparing the residual sum of squares obtained from the restricted regression (based on common parameters) with the residual sum of squares from the unrestricted specification (based on varying parameters). The test statistic has an F-distribution under the null hypothesis. The calculated test statistic suggested that the null hypothesis could not be rejected at the 5% level of significance, although the result was somewhat borderline for the Data4 sub-sample.

Application of zero coupon Nelson-Siegel yield curves to estimate par yield curves (section 5 of this report)

The Nelson-Siegel model is a form of multi-factor, affine term structure model (ATSM), because it is a parametric, parsimonious form of the forward rate function (Christensen et al, 2011). As explained by Nelson and Siegel (1987), the discount rate function is obtained by integrating a forward rate function which is itself the solution to a second-order differential equation with real and unequal roots.

An important contribution of this report has been the development of par yield curves, which are a theoretically correct form of yield curve because the relationship between term to maturity and yield is modelled after adjusting the observations on bond yields for differences in coupon rates. An extended Nelson-Siegel method was applied, following a technique that has been described by Ferstl and Hayden (2010) and Bliss (2007). In the first instance, the method involved constructing a zero coupon curve or spot rate curve by fitting the discount rate function directly to bond prices. An objective function was used which minimised the weighted squared value of the difference between fitted bond prices and actual prices (or "dirty" prices). The fitted prices were derived by discounting a stream of cash flows from the bond. The discount rates, in turn, were determined from the estimation of the Nelson-Siegel equation.

When minimising the unweighted price errors (the square of the difference between the fitted price and the actual price), bonds with a longer maturity obtain a higher weighting, due to a higher degree of price sensitivity, which leads to a less accurate fit at the short end of the spot curve. Therefore, a weighting of the price errors has to be introduced to solve this problem, or to reduce the degree of heteroscedasticity, if this latter condition has affected the regression disturbances.

To quantify the sensitivity of a bond's price against changes in the interest rate, one needs to account for the fact that coupons are paid during the lifetime of a coupon bond. A standard measure of risk is the Macaulay duration, which computes the average maturity of a bond using the present values of its cash flows as weights.

Macaulay duration was used as the weighting scheme under the extended Nelson-Siegel formulation. The contribution of the inverse duration of each bond to the sum of the inverse durations of all bonds was used to determine the weight allocated to each bond.

The spot rate curve or discount rate function was estimated first. Thereafter, a par yield curve was constructed by calculating a series of coupon payments which corresponded to the estimated spot rates. The assumption made was that coupon payments would be paid on a semi-annual basis. The relationship between the spot rate curve and the par yield curve is explained by Schaefer (1977). A bond that trades at its 'par' value is a bond for which the coupon rate is equal to its yield.

The estimated spot rate curve is shown in Figure 15. The results for the par yield curve are presented in Figure 17 and Table 11. The estimated cost of debt for a 10-year tenor bond was calculated to be 6.49% over the reference period. This figure is an average of the daily results for February 2013.

The daily observations of the risk-free rate were subtracted from the daily results for the par yields, so as to derive estimates of the debt risk premium. The monthly average of the debt risk premium was evaluated to be 2.98%.

Comparison of results from yield curves with those obtained using the methods applied separately by the AER and the Economic Regulation Authority (WA) (section 6 of this report)

In its draft decision for Aurora, the AER estimated the debt risk premium for a benchmark, 10 year corporate bond by calculating an arithmetic average of the yields on a set of nine bonds[1]. The ERA (WA) has advocated a 'joint-weighted' estimation method for determining the DRP which is given by:

$$\frac{\sum_i (\text{Maturity}_i) \times (\text{Issue Amount}_i) \times (\text{DRP}_i)}{\sum_i (\text{Maturity}_i) \times (\text{Issue Amount}_i)}$$

where:

Maturity_i	=	The remaining term to maturity of a particular bond (to be distinguished from the tenor at issuance).
Issue Amount_i	=	The size of the bond at issuance, measured in $ million. For a plain vanilla, fixed coupon bond, the issue amount can be thought of as the bond's face value.
DRP_i	=	The debt risk premium attributable to the particular bond (bond 'i').

Two simulation exercises were conducted so as to compare results under the approaches adopted separately by the AER and the ERA (WA) with the outcomes from yield curve analysis.

Debt risk premium based on simple averaging (section 6.1)

Under the simple averaging approach, nine bonds with a term to maturity of between 7 years and 13 years were sampled, and the yield for each bond was calculated using the equation fited to Data2 by R `nls` (see, section 3.5). The equation used the data that had been averaged over the reference period. The DRP for each individual bond was worked out by subtracting the risk-free rate, for a commensurate term to maturity, from the predicted yield. The average DRP was then calculated for the bond sample by taking an arithmetic mean. The simulation was repeated 10,000 times, and the results were recorded and summarised into a histogram. A summary of the outcomes from the simulation is presented in Figure 18. The distribution of results was compared against the estimated DRP of 2.96% shown in Table 6. Note that the model evaluated DRP of 2.96% is the actual result that is obtained by reading off the yield curve at 10 years.

[1] AER (2011), Draft Distribution Determination, Aurora Energy Pty Ltd, 2012-2013 to 2016-2017, Australian Energy Regulator, November 2011, Table 9.7, page 241.

The output from the simulation demonstrated unequivocally that the AER's method of simple averaging delivers downwardly biased estimates of the DRP. The reason for the downward bias is that the calculation of arithmetic means does not impose proper controls for term to maturity. Yield curves capture the correct form of the relationship between term to maturity and the cost of debt. If the yield curve is concave at a particular point, then the average DRP from a bond sample will be less than the DRP at the average term to maturity.

Debt risk premium based on the joint-weighted DRP approach of the ERA (WA)

The simulation of outcomes under the joint-weighted approach used by the ERA (WA) was performed by taking samples of bonds with a term to maturity of greater than 7 years. The objective of the exercise was to assess the results that would be obtained if the ERA's method were used to estimate the cost of debt for a 10 year tenor bond. The ERA currently adopts a 5-year term for estimating the debt risk premium and the risk-free rate.

We used bootstrap resampling (see, for example, Efron and Tibshirani, 1996) to examine the statistical properties of the joint-weighted approach. Thus, to implement the ERA's approach on each of the four data sub-samples, we performed the following 1,000 times: We sampled with replacement a dataset of the same size as the particular sub-sample being examined. For dataset Data1, there were 260 observations in the sub-sample, however the number of bonds with a term to maturity of greater than 7 years was 63. The joint-weighted DRP was calculated for the sampled dataset. When the results were obtained for 1,000 replications, then the mean result for the DRP, and the standard deviation, were computed. The mean is used to determine the bias, while the standard deviation of the 1,000 debt risk premium results gives an empirically determined standard error for the procedure.

At the same time, we performed bootstrap resampling of the Nelson-Siegel curve fitting approach. For each of the four data sets, we performed a similar operation 1,000 times: We sampled with replacement a dataset with the same number of observations as the sub-sample being considered. For the sampled dataset, we estimated the Nelson-Siegel model, then computed the yield for a term to maturity of 10 years, and then transformed the result into a debt risk premium. Again, we recorded the mean and standard deviation from the samples so as to provide values for the bias and the standard error of the Nelson-Siegel approach.

The method used by the ERA (WA) was found to give biased results across all four data sub-samples. If the yield curve was concave at a particular term to maturity, then the ERA's method would deliver a downwardly biased estimate of the DRP. In addition, the Nelson-Siegel approach gave consistently smaller standard errors.

Conclusions (section 7)

Nelson-Siegel curves can be used to estimate term structure models which provide an appropriate and accurate method of determining the cost of debt for different tenors.

CEG (2013a, 2013b) applied Nelson-Siegel equations across a broad database of corporate bonds, and obtained estimates of the debt risk premium which were marginally below 3.0% for a 10 year term to maturity. We have concentrated on the output that was generated by the four main data sub-samples used by CEG, and have been able to produce results that either closely matched those of CEG or else were identical. After undertaking limited re-parameterisation, we were also able to produce standard errors, thereby providing a useful complement to the analysis already undertaken by CEG. Standard errors convey information about the precision of the empirical estimates. The results for the debt risk premium at 10-years, and for the increment to the DRP from 7 to 10 years, were shown to have low standard errors and to therefore be precise.

The non-linear mixed effects model is a robust specification which makes full use of the information that is contained within the daily observations of bond yields. The model takes account of the idiosyncratic aspects of a particular bond and also controls for serial correlation of the daily bond yields. For the largest sub-sample of data, the estimated DRP was 2.99% for a 10 year tenor bond, with a standard error of 0.09%.

The estimation of par yield curves is a worthy exercise because these curves fully standardise and correct for differences between bonds that are caused by variations in the timing and size of coupon payments. We estimated zero-coupon yield curves or spot rate curves that belong to the family of Nelson-Siegel curves. Subsequently, we used these estimates to generate estimates of par yield curves. Schaefer (1977) shows how one can uncover the term structure of par yields from the term structure of spot rates.

Finally, the application of a simulation technique has shown that the curve-fitting method can overcome the deficiencies of both the simple averaging approach (previously applied by the AER), and the joint-weighted averaging approach advocated by the ERA (WA). The two approaches give downwardly biased estimates of the DRP, and the joint-weighted approach is also less precise than using curve-fitting. The loss of precision under the joint-weighted DRP technique is shown by comparatively high values of the mean-squared error (MSE).

2 Terms of reference: review of fair value curves and an assessment of methods used to determine the spot cost of debt

Background

On 30th August 2013, the Australian Energy Regulator (AER) published its draft rate of return guideline that will form the basis of the regulated rate of return to be applied in energy network decisions made from 2014 onwards. Previously the AER published an Issues Paper on 18th December 2012 and a Consultation Paper on 10th May 2013.

Under the new Rules, promulgated by the Australian Energy Market Commission, (AEMC), in December 2012, fundamental changes have been made to the way in which the allowance for the return of debt can be determined. Clause 6.5.2(j) of the National Electricity Rules (NER) provides that, at each determination, the allowance for the return of debt can be computed in one of three different ways:

1. The return that would be required by debt investors in a benchmark efficient entity if it raised debt at the time or shortly before the making of the distribution determination for the regulatory control period.

2. The average return that would have been required by debt investors in a benchmark efficient entity if it raised debt over an historical period prior to the commencement of a regulatory year in the regulatory control period; or

3. Some combination of the returns referred to in subparagraphs (1) and (2).

Implicit in these considerations is that the regulatory framework should encourage efficient financing practices that the previous approach did not explicitly consider.

The calculation of the spot cost of debt, or the market cost of debt at a particular point in time remains an essential component of all three of the aforementioned approaches. Option one, which is known as the rate-on-the day approach, uses an estimate of the cost of debt that is determined over a limited number of days in advance of the commencement of a new regulatory period. Option two calculates a form of historical average cost of debt, using historic information on spot rates. Under option three, the base cost of debt may be estimated separately from the debt risk premium.

United Energy and Multinet Gas are seeking a suitably qualified consultant to undertake specific analysis in relation to the current cost of debt, as measured over a recent 20 to 30 day averaging period. The purpose of the current exercise is to investigate whether yield curves can be used to derive robust estimates of the cost of debt for a benchmark corporate bond with a ten-year tenor.

The consultant will be supplied with:

- A spread sheet database containing information about the characteristics of bonds used in the empirical analysis. The attributes covered will include credit ratings, maturity dates, and yields. Data covering plain vanilla bonds will, in the main, be provided, although there may also be results for callable bonds and other types of bonds. Both domestic and foreign currency bonds will be supplied, although the yields on the latter will have been swapped into Australian dollar yields.

- A report from CEG which contains empirical estimates of yield curves. Please refer to: Estimating the debt risk premium (Incorporating CEG notice of errata, 22nd August 2013), prepared for the Energy Networks Association by the Competition Economists Group, August 2013. The report discusses yield curves that have been estimated according to the methods of Nelson and Siegel (1987) . The report also contains an assessment of the performance of the Bloomberg fair value curve for BBB+ corporate debt.

- Regression results will have been reported in a spread sheet workbook. Program code may be supplied if it is available.

Scope of work

The consultant is required to undertake a detailed review of the yield curves that have been estimated by CEG, with a view to assessing the merits of the overall approach. The yield curves are a tool for working out the benchmark cost of debt corresponding to a particular term to maturity. The Nelson-Siegel model is non-linear in the parameters and is therefore more complicated to fit than a normal regression model.

The consultant should assess the case for using yield curves by comparison with the method of direct averaging of observed bond yields. The direct averaging technique takes a simple arithmetic average of bond yields, and has been applied by the AER and the Economic Regulation Authority (Western Australia).

The consultant should also develop yield curves for zero coupon bonds, and par yield curves. A zero coupon bond is a fixed income investment that provides only one payment at maturity. Bonds which trade at par are those for which the calculated yield is equal to the coupon rate. Par yield curves provide a theoretically correct specification for the term structure of the cost of debt.

Preliminary review of CEG methods

1. Investigate the equations which have been estimated by CEG and seek to reproduce the reported results using a suitable software package. Categorise the results from yield-to-maturity curves separately from the results for par value yield curves. Assess how the estimated equations vary according to the bond samples used.

2. Examine and report on the accuracy and correctness of the results from the estimated equations. Check whether outliers are present, and review the regression diagnostics. Note the standard errors and report on the precision of the parameter estimates.

3. Assess whether the estimates of the cost of debt that have been presented by CEG are justifiable in the context of the estimated yield curves.

Refinements to the analysis for both types of yield curve

4. Investigate the case for the use of alternative estimation methods, such as robust regression techniques, for the daily regressions. Compare the results from different estimation methods.

5. Examine the day-to-day drift of the parameter estimates over the nominated days of the averaging period. Suggest an alternative method for combining the daily results for the estimated benchmark 10-year corporate bond yield.

6. Examine the validity of restrictions that may be imposed upon the Nelson-Siegel curves. The types of restriction are likely to include different intercept terms for bonds in different credit rating bands.

7. The empirical methods that are applied to derive par value yield curves are more advanced. Firstly, a zero coupon yield curve is estimated. Secondly, a further non-linear equation has to be solved in order to determine par value yields. Diagnostic tests are needed for the overall model, and these should be developed by the consultant. The consultant should also investigate the impact of the weighting scheme based on Macaulay duration .

8. Evaluate the results for the cost of debt that have been determined as par value yields. Comment on the methods that have been applied.

Comparison of results from yield curves with those obtained using the methods applied separately by the AER and the Economic Regulation Authority (WA).

9. Critically assess the statistical properties of the cost of debt estimators developed separately by the AER and the ERA (WA). Consider the use of an overall measure of usefulness such as mean squared error (which is equal to the sum of the variance and the bias squared).

10. Undertake a simulation analysis and apply other methods as appropriate.

Timeframe

The consultant is to provide a draft report which discusses the results of the analysis by Monday 23rd September 2013. A final report should be provided by no later than Monday 7th October.

Reporting

Jeremy Rothfield will serve as the primary contact for the period of the engagement. The consultant will prepare reports showing the work-in-progress on a regular basis. The consultant will make periodic presentations on analysis and advice as appropriate.

The consultant is likely to be called upon to present analysis and advice to the cost of capital sub-group of the Energy Networks Association (ENA).

Conflicts

The consultant is to identify any current or potential future conflicts. Compliance with the Code of Conduct for Expert Witnesses Attached is a copy of the Federal Court's Practice Note CM 7, entitled Expert Witnesses in Proceedings in the Federal Court of Australia, which comprises the guidelines for expert witnesses in the Federal Court of Australia (Expert Witness Guidelines).

Please read and familiarise yourself with the Expert Witness Guidelines, and comply with them at all times in the course of your engagement with United Energy and Multinet Gas.

In particular, your report prepared for United Energy and Multinet Gas should contain a statement at the beginning of the report to the effect that the author of the report has read, understood and complied with the Expert Witness Guidelines.

Your report must also:

1. Contain particulars of the training, study or experience by which the expert has acquired specialised knowledge.

2. Identify the questions that the expert has been asked to address.

3. Set out separately each of the factual findings or assumptions on which the expert's opinion is based.

4. Set out each of the expert's opinions separately from the factual findings or assumptions.

5. Set out the reasons for each of the expert's opinions; and

6. Otherwise comply with the Expert Witness Guidelines.

The expert is also required to state that each of the expert's opinions is wholly or substantially based on the expert's specialised knowledge. The declaration contained within the report should be that "[the expert] has made all the inquiries that [the expert] believes are desirable and appropriate and that no matters of significance that [the expert] regards as relevant have, to [the expert's] knowledge, been withheld from the report".

Please also attach a copy of these terms of reference to the report.

Fees

The consultant is requested to submit:

- A fixed total fee for the project and hourly rates for the proposed project team should additional work be required; and
- Details of the individuals who will provide the strategic analysis and advice.

Contacts

Any questions regarding this terms of reference should be directed to:
Jeremy Rothfield
telephone (03) 8846 9854
or via email at Jeremy.Rothfield@ue.com.au

3 Review of CEG methods and analysis of regression diagnostics

In our review of the CEG report, we have:

- Confirmed that the estimated parameters of the yield curves provided by CEG for the various bond samples match those which we have calculated.
- Performed regression diagnostics to determine the validity or otherwise of the assumptions on which the estimated parameters depend.
- Given standard errors of the parameters in order to define the precision of the yield curves.
- Based on this empirical work, given an opinion of whether the estimates for the cost of debt provided by CEG are justifiable.

The Nelson-Siegel model can be written as

$$\begin{aligned}\text{Yield}(t, \text{rank}) &= \beta_{1,\text{rank}} + (\beta_2 + \beta_3)\frac{1 - \exp(-t/\beta_0)}{t/\beta_0} - \beta_3 \exp(-t/\beta_0) \\ &= \beta_1 + (\beta_2 + \beta_3)\frac{1 - \exp(-t/\beta_0)}{t/\beta_0} - \beta_3 \exp(-t/\beta_0) + \beta_4\text{A-} + \beta_5\text{BBB}\end{aligned}$$

where t is the remaining term to maturity of the bond, A- and BBB are dummy variables for A- and BBB bonds respectively. Hence the asymptote of the Nelson-Siegel curve as $t \to \infty$ is β_1 for BBB+ bonds, $\beta_1 + \beta_4$ for A- bonds, and $\beta_1 + \beta_5$ for BBB bonds.

In this formulation, $\beta_1 + \beta_2$ can be regarded as the "short-term" component, β_3 can be regarded as the "medium-term component", while β_1 can be regarded as the "long-term" component. Ferstl and Hayden (2010) interepret the parameters as follows[2]:

- β_1 is the asymptotic value of the spot rate function which can be seen as the long term interest rate. Due to the assumption of positive interest rates, it is required that $\beta_1 > 0$.
- β_2 determines the rate of convergence with which the spot rate function approaches its long term trend. The slope will be negative if $\beta_2 > 0$ and vice versa.
- The instantaneous short rate is given by $\beta_1 + \beta_2$, which is constrained to be greater than zero.
- β_3 determines the size and form of the hump. $\beta_3 > 0$ results in a hump at β_0 whereas $\beta_3 < 0$ produces a U-shape.

[2] Ferstl and Hayden use a different, but equivalent, formulation of the Nelson-Siegel model. In our description of Ferstl and Hayden's interpretation, we have translated their interpretation into the formulation we have used.

- It is required that $\beta_0 > 0$.

The appropriate extra constraints for the Nelson-Siegel model with the additional parameters β_4 and β_5 are:

$$\begin{aligned} \beta_4 &\leq 0 \\ \beta_5 &\geq 0 \end{aligned}$$

which implies that

$$-(\beta_1 + \beta_2) < \beta_4 < 0.$$

3.1 Confirmation of CEG parameter estimates

Table 4A of CEG (2013b) gives Debt Risk Premiums (DRPs) for 32 different groups of bonds. In the CEG report, for each group of bonds, defined by the rating class (BBB+ only; or A-, BBB+ and BBB), currency (AUD or All), type (i.e. options or no options), source (Bloomberg only or both Bloomberg and UBS), and country of origin (Australia or All), the Nelson-Siegel curve (Nelson and Siegel, 1987) was fitted, and the 7 year DRP and 10 year DRP were calculated with

$$\begin{aligned} \text{DRP}_7 &= \text{Yield}(7) - 3.244\% \\ \text{DRP}_{10} &= \text{Yield}(10) - 3.515\% \end{aligned} \tag{1}$$

and

$$\Delta\text{DRP} = \frac{100(\text{DRP}_{10} - \text{DRP}_7)}{3}.$$

The values 3.244% and 3.515% represent the average yields on 7 year and 10 year Commonwealth Government securities, respectively, measured over February, 2013. These yields were calculated by CEG using an interpolation method that was applied to daily data sourced from Table F16 from the RBA website. A monthly average was taken of the daily results for 7-year and 10-year CGS yields.

Table 1 gives the comparison between the results obtained in the CEG report[3] and those using the `optim`[4] command in the R environment for statistical computing and graphics (R Core Team, 2013) for the four main groups of bonds considered by CEG. The results from the report, obtained using Excel Solver, are very similar to the results using R `optim`.

							CEG (2013b) Report			R optim		
Row	Ratings	Curr.	Type	Source	Country of domicile	# Bonds	DRP_7 (%)	DRP_{10} (%)	Δ DRP (bppa)	DRP_7 (%)	DRP_{10} (%)	Δ DRP (bppa)
1	All	All	All	BB	All	260	2.76	2.99	7.62	2.76	2.99	7.59
2	All	All	All	BB	AU	221	2.76	2.99	7.38	2.76	2.98	7.35
3	All	All	All	BB & UBS	All	307	2.78	2.98	6.67	2.77	2.97	6.64
4	All	All	All	BB & UBS	AU	258	2.76	2.96	6.71	2.76	2.96	6.68

Table 1: Comparison of the results given in Table 4A of CEG (2013b), and those calculated using R `optim` package.

Table 2 gives the parameter estimates using Solver and those obtained by R `optim`, as well as the residual sum of squares (RSS) and calculated DRP_7, DRP_{10}, and ΔDRP.

Row	Source	$\hat{\beta_0}$	$\hat{\beta_1}$	$\hat{\beta_2}$	$\hat{\beta_3}$	$\hat{\beta_4}$	$\hat{\beta_5}$	RSS	DRP_7 (%)	DRP_{10} (%)	ΔDRP (bppa)
1	Report	1.405	7.771	-2.928	-6.162	-0.461	0.577	1604.391	2.76	2.99	7.62
1	R optim	1.405	7.771	-2.928	-6.163	-0.461	0.577	1604.355	2.76	2.99	7.59
2	Report	1.365	7.737	-2.869	-6.263	-0.471	0.572	1395.284	2.76	2.98	7.38
2	R optim	1.364	7.737	-2.868	-6.264	-0.471	0.572	1395.259	2.76	2.98	7.35
3	Report	1.556	7.722	-3.206	-4.794	-0.507	0.524	1888.033	2.78	2.98	6.67
3	R optim	1.556	7.722	-3.206	-4.794	-0.507	0.524	1888.006	2.77	2.97	6.64
4	Report	1.541	7.708	-3.207	-4.858	-0.517	0.542	1629.828	2.76	2.96	6.71
4	R optim	1.541	7.708	-3.207	-4.858	-0.517	0.542	1629.808	2.76	2.96	6.68

Table 2: Parameter estimates and residual sum of squares using R `optim` package for Rows 1 to 4.

3.2 Methods of optimisation

3.2.1 Excel Solver

EXCEL Solver uses the Generalized Reduced Gradient (GRG2) algorithm (Lasden et al., 1968). It uses finite differences to calculate the Jacobian or gradient vector. The problem is scaled by dividing all

[3]Note that the results given in the "Report" columns actually correspond to those given in the Addendum report issued by CEG, i.e. CEG (2013b)

[4]`optim` is a general purpose optimisation method. The BFGS quasi-Newton method was used, (from the user guide: "specifically, that published in 1970 by Boyden, Fletcher, Goldfarb, and Sharmo. This uses function values and gradients to build up a picture of the surface to be optimised."

variables by their initial values. The GRG2 algorithm will stop when it finds a local optimal solution, that is when the Kuhn-Tucker conditions are satisfied to within a convergence tolerance. However it may also stop when it meets the requirements of a ”slow progress” test: The relative change in the objective function is less than the convergence tolerance for the last five iterations.

3.2.2 R `optim`

The function “optim” in R is based on a quasi-Newton algorithm. In a Newton algorithm, the function to be optimised is approximated as a quadratic function of the parameters. The iterative scheme is given by

$$\beta_{k+1} = \beta_k + \gamma H^{-1} g$$

where H is the Hessian, the matrix of second derivatives of the function with respect to the parameters, g is the gradient, the vector of first derivatives, and γ is a step size factor. For a pure Newton algorithm, $\gamma = 1$, but usually γ is varied to ensure improvement from iteration to iteration. In the quasi-Newton BFGS algorithm, the Hessian is not calculated directly but replaced with an approximation which is updated as the iterations proceed. The algorithm converges if the current iteration has not been able to reduce the function by a factor of approximately 10^{-8}. When there are constraints, the L-BFGS algorithm is used, although it is often simpler to ignore the constraint and then examine whether the solution satisfies the constraints and, if not, then implement the constrained solution.

3.2.3 R `nls`

The function “nls” in R uses a Gauss-Newton method, which takes advantage of the fact that the function to be optimised is a sum of squares function, and hence the Hessian can be approximated as a function of the gradient. In `nls`, convergence is achieved when a relative offset criteria is satisfied, which is a superior method than just monitoring lack of progress. One problem with Gauss-Newton methods is the selection of starting values and if these are inappropriate then failure to converge may occur. One alternative is the method of steepest descent which is only based on the gradient vector. The method of steepest descent can be very much slower then the Gauss-Newton method but is much more robust to bad starting values. Even better, the Levenberg-Marquardt algorithm acts like the method of steepest descent when far from the optimal value but more like the Gauss-Newton method when close to the solution. This algorithm has been implemented in the `nlsLM` command in the `minpack.LM` package with the same input and output facilities as `nls`. Again there are algorithms to handle constraints and also to handle conditionally linear problems, but it is often easier to use the standard calling functions.

3.3 Regression diagnostics

The four rows in Table 1 are called Data1, Data2, Data3, and Data4 in this report. In the CEG report, CEG (2013b), the individual yields for each day and each bond were used as input to the Excel Solver. The use of daily data in this way would be unlikely to have much effect on the parameter estimates but would almost certainly affect the calculation of the standard errors because there is usually very little change in the yield of an individual bond from day to day. To overcome the limitations of the use of daily data in this manner, the average yield and average term to maturity were calculated over the month of February 2013, with the resulting values then employed as inputs. A more refined estimation method, which uses the daily data, has also been implemented and is discussed in a later section. The latter method gives similar estimates but more refined standard errors.

Standard errors from a non-linear regression rely on an assumption that the non-linear mean function, as a function of the parameters, can be approximated locally by a linear function. To examine whether the linear approximation is appropriate, the profile t function (see, for example, Bates and Watts, 1988) defined by

$$\tau(\beta_j) = \text{sign}(\beta_j - \hat{\beta}_j)\frac{\sqrt{\text{RSS}(\beta_j) - \text{RSS}(\hat{\beta})}}{s}$$

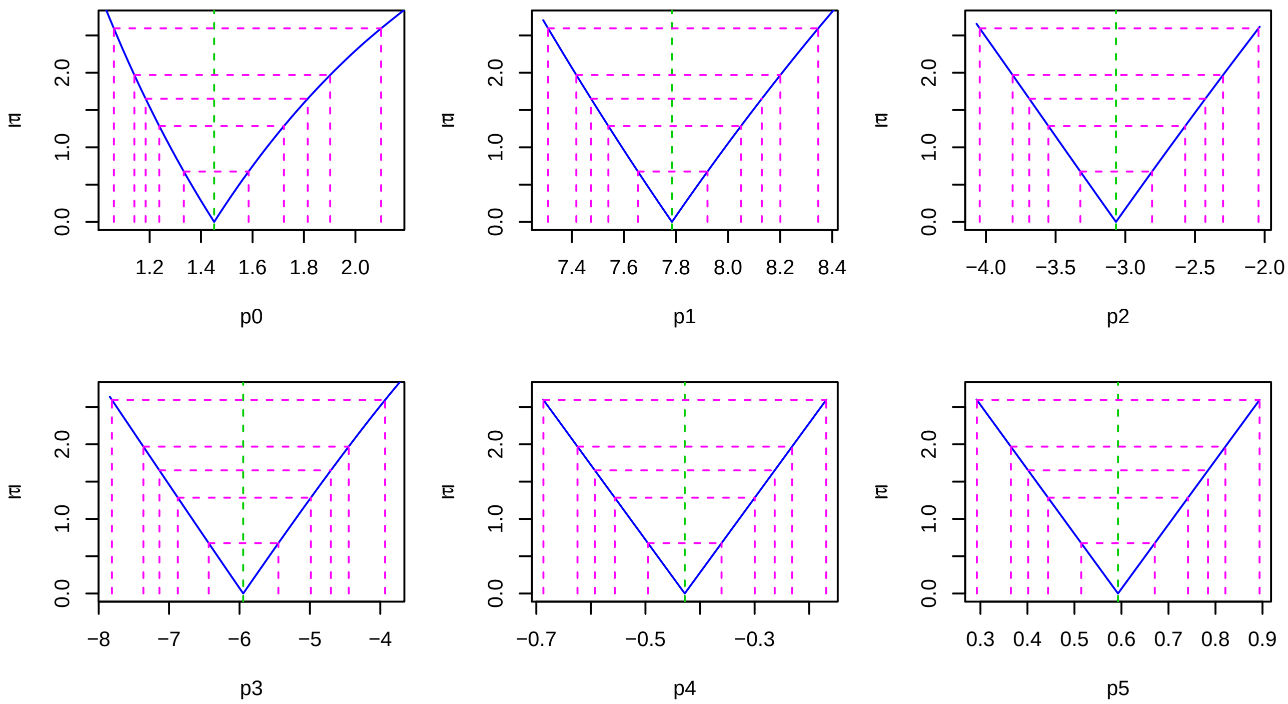

Figure 1: Profile t plots for the original Nelson-Siegel model. The dotted lines correspond to 50%, 80%, 90%, 95%, and 99% confidence intervals.

is plotted, where β_j is a parameter of interest with estimate $\hat{\beta}_j$, $\text{RSS}(\hat{\beta})$ is the residual sum of squares at the solution, $\text{RSS}(\beta_j)$ is the residual sum of squares holding the jth parameter at β_j, and s is the residual standard error. By default, the absolute value of τ_j is plotted.

Figure 1 shows the profile t functions for all six parameters. The x-axis shows the value of β_j while the y-axis shows the corresponding absolute value of τ_j. The parameters β_1 to β_5 are well-behaved. However, β_0 shows some curvature, suggesting that confidence intervals based on standard errors for this parameter may not be accurate. In addition, confidence intervals for functions of the parameters, such as

$$\text{DRP}_{10} = \beta_1 + (\beta_2 + \beta_3)\frac{1 - \exp(-10/\beta_0)}{10/\beta_0} - \beta_3 \exp(-10/\beta_0)$$
$$\text{DRP}_7 = \beta_1 + (\beta_2 + \beta_3)\frac{1 - \exp(-7/\beta_0)}{7/\beta_0} - \beta_3 \exp(-7/\beta_0)$$

and

$$\Delta\text{DRP} = \frac{100(\text{DRP}_{10} - \text{DRP}_7)}{3},$$

may also not be appropriate, because of the non-linear behaviour of β_0.

To overcome this, β_0 was re-parameterised as

$$\beta_6 = \log(\beta_0).$$

This re-parameterisation does not change the model, but improves the estimation of it. The re-parameterised Nelson-Siegel model is

$$\text{Yield}(t, \text{rank}) = \beta_1 + (\beta_2 + \beta_3)\frac{1 - \exp(-t/\exp(\beta_6))}{t/\exp(\beta_6)} - \beta_3 \exp(-t/\exp(\beta_6)) + \beta_4\text{A-} + \beta_5\text{BBB}.$$

Figure 2 gives the profile t functions for the revised model. The curvature shown in Figure 1 has been almost entirely removed.

Under the original parameterisation, the estimated β_0 parameter is 1.4510 with a standard error of 0.2119. A 95% confidence interval based on $\pm$ 1.96 standard errors would be inappropriate since the

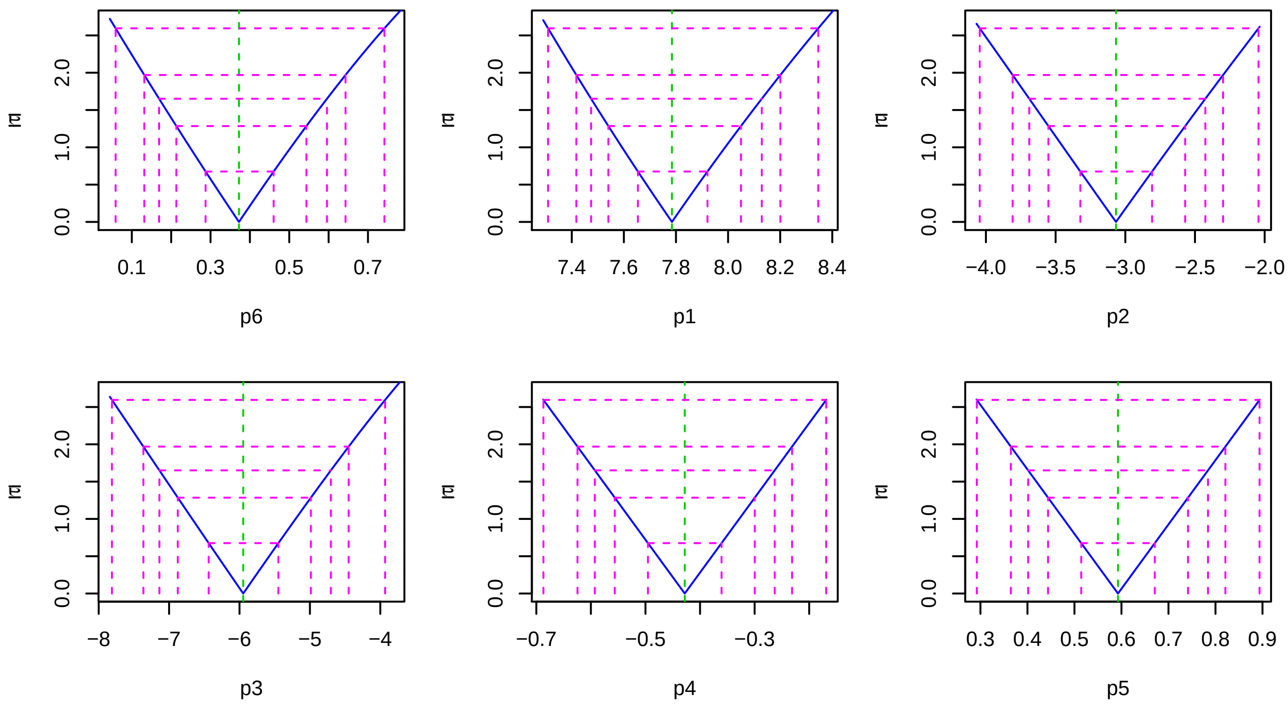

Figure 2: Profile t plots for the revised Nelson-Siegel model

correct confidence interval, based on the profile likelihood function, is (1.1408,1.9022). The asymmetry of the correct confidence interval can be computed as

$$\frac{(\text{Upper Limit} - \text{Estimate})}{(\text{Estimate} - \text{Lower Limit})} = \frac{(1.9022 - 1.4510)}{(1.4510 - 1.1408)} = 1.4545$$

and so clearly a symmetric confidence interval is not a good summary of the uncertainty attached to the β_0 parameter. On the other hand, the estimated β_6 parameter is 0.3722 with a standard error of 0.1460. The correct confidence interval, based on the profile likelihood function, is (0.1317,0.6430), with a asymmetry of

$$\frac{(0.6430 - 0.3722)}{(0.3722 - 0.1377)} = 1.1548.$$

which is clearly closer to 1.

3.4 Reparameterisation to find Yields at 7 years and 10 years directly

Rather than estimating the Nelson-Siegel model and then substituting maturities of 7 years and 10 years into the fitted function to obtain yields at 7 years and 10 years respectively, it is possible to re-write the equation in order to estimate these quantities directly.

For example, for 10 years maturity, we have

$$\begin{aligned}\text{Yield}(10, \text{rank}) &= \beta_{1,\text{rank}} + (\beta_2 + \beta_3)\frac{1 - \exp(-10/\beta_0)}{10/\beta_0} - \beta_3 \exp(-10/\beta_0) \\ &= \beta_1 + (\beta_2 + \beta_3)\frac{1 - \exp(-10/\beta_0)}{10/\beta_0} - \beta_3 \exp(-10/\beta_0) + \beta_4\text{A-} + \beta_5\text{BBB}\end{aligned}$$

and hence

$$\begin{aligned}\text{Yield}(t) = \text{Yield}(10) + (\beta_2 + \beta_3)\left(\frac{1 - \exp(-t/\beta_0)}{t/\beta_0} - \frac{1 - \exp(-10/\beta_0)}{10/\beta_0}\right) \\ - \beta_3\left(\exp(-t/\beta_0) - \exp(-10/\beta_0)\right) + \beta_4\text{A-} + \beta_5\text{BBB}.\end{aligned}$$

In this reparameterised equation the parameter β_1 has been replaced by the parameter Yield(10). Table 3 gives the parameter estimates and standard errors for Data1 using the original parameterisation in section 3.3 and Table 4 gives the parameter estimates and standard errors for the revised parameterisation.

	Estimate	Std. Error	t value	Pr(>|t|)
p6	0.37	0.15	2.55	0.01
p1	7.78	0.21	36.82	0.00
p2	-3.07	0.42	-7.27	0.00
p3	-5.95	0.77	-7.71	0.00
p4	-0.43	0.10	-4.25	0.00
p5	0.59	0.12	5.07	0.00

Table 3: Regression parameters and standard errors for fitted Nelson-Siegel model: Original parameterisation.

	Estimate	Std. Error	t value	Pr(>|t|)
p6	0.37	0.15	2.55	0.01
p10	6.48	0.09	68.52	0.00
p2	-3.07	0.42	-7.27	0.00
p3	-5.95	0.77	-7.71	0.00
p4	-0.43	0.10	-4.25	0.00
p5	0.59	0.12	5.07	0.00

Table 4: Regression parameters and standard errors for fitted Nelson-Siegel model: Revised parameterisation after substituting in the formulation for Yield(10). Note that the parameter estimate p10 is in fact the estimated yield at 10 years.

Figure 3 gives the profile t plot with the yield at 10 years as a parameter. This parameter has a well-behaved profile plot, indicating that the usual confidence intervals can be used.

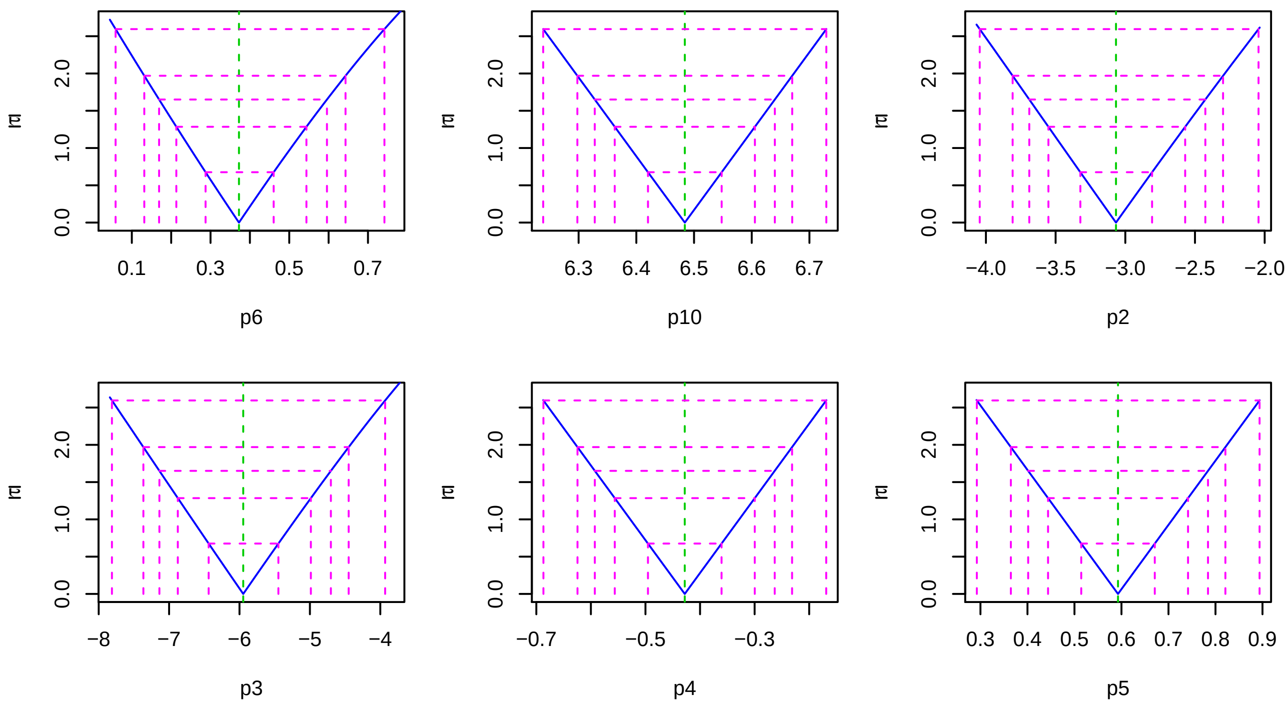

Figure 3: Profile t plots for the Nelson-Siegel model with yield at 10 years maturity as a parameter.

A similar calculation can be done for the yield at 7 years maturity, where we have

$$\begin{aligned}\text{Yield}(7, \text{rank}) &= \beta_{1,\text{rank}} + (\beta_2 + \beta_3)\frac{1 - \exp(-7/\beta_0)}{7/\beta_0} - \beta_3 \exp(-7/\beta_0) \\ &= \beta_1 + (\beta_2 + \beta_3)\frac{1 - \exp(-7/\beta_0)}{7/\beta_0} - \beta_3 \exp(-7/\beta_0) + \beta_4\text{A-} + \beta_5\text{BBB}\end{aligned}$$

and hence

$$\begin{aligned}\text{Yield}(t) = \text{Yield}(7) &+ (\beta_2 + \beta_3)\left(\frac{1 - \exp(-t/\beta_0)}{t/\beta_0} - \frac{1 - \exp(-7/\beta_0)}{7/\beta_0}\right) \\ &- \beta_3\left(\exp(-t/\beta_0) - \exp(-7/\beta_0)\right) + \beta_4\text{A-} + \beta_5\text{BBB}.\end{aligned}$$

Table 5 gives the parameter estimates and standard errors for the revised reparameterisation after substituting in the formulation for Yield(7).

	Estimate	Std. Error	t value	Pr(>|t|)
p6	0.37	0.15	2.55	0.01
p7	5.98	0.10	59.59	0.00
p2	-3.07	0.42	-7.27	0.00
p3	-5.95	0.77	-7.71	0.00
p4	-0.43	0.10	-4.25	0.00
p5	0.59	0.12	5.07	0.00

Table 5: Regression parameters and standard errors for fitted Nelson-Siegel model: Revised parameterisation after substituting in the formulation for Yield(7). Note that the parameter estimate p7 is in fact the estimated yield at 7 years.

Figure 4 give the profile t plot with the Yield at 7 years as a parameter. This parameter also has a well-behaved profile plot, indicating again that the usual confidence intervals can be used.

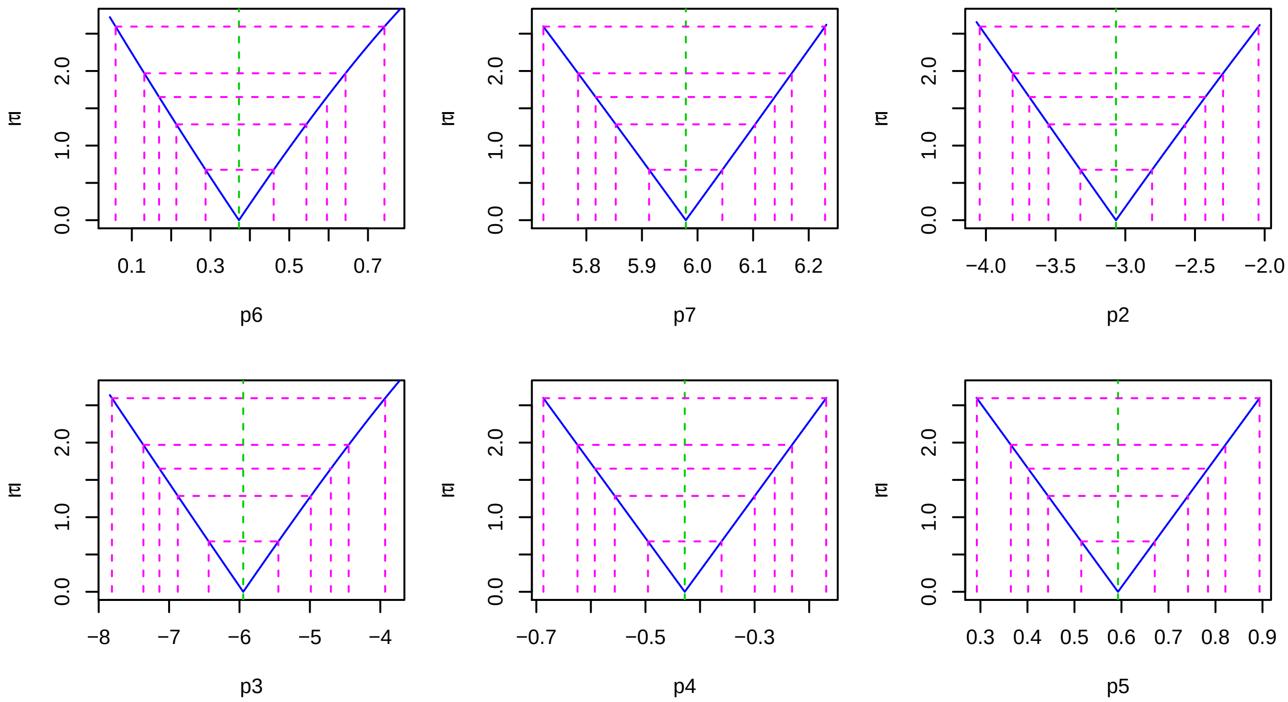

Figure 4: Profile t plots for the Nelson-Siegel model with yield at 7 years maturity as a parameter.

3.5 Fitting the Nelson-Siegel model to the four data sets

The reparameterised Nelson-Siegel model was fitted to the Data1, Data2, Data3, and Data4 data sets. Estimates of the DRP_7, DRP_{10} and $\Delta(DRP)$ were found by inserting the applicable term to maturity into the equation for which coefficients had already been empirically determined. Standard errors were found using the delta method[5]. Estimates and standard errors are given in Table 6.

One point to notice is that the standard errors for ΔDRP appear to be large. However, the units for ΔDRP are bppa. If the units were quoted as percentages, then for Data1 the standard error would be 0.0163.

			7 year DRP		10 year DRP		ΔDRP	
Data Set	Source	Data	Estimate (%)	Std.err	Estimate (%)	Std.err	(bppa)	Std.err
Data1	Report	Individual	2.76		2.99		7.62	
	optim	Individual	2.76		2.99		7.59	
	nls	Average	2.73	0.1	2.97	0.09	7.8	1.63
Data2	Report	Individual	2.76		2.99		7.38	
	optim	Individual	2.76		2.98		7.35	
	nls	Average	2.73	0.11	2.96	0.1	7.58	1.72
Data3	Report	Individual	2.78		2.98		6.67	
	optim	Individual	2.77		2.97		6.64	
	nls	Average	2.76	0.09	2.96	0.09	6.78	1.49
Data4	Report	Individual	2.76		2.96		6.71	
	optim	Individual	2.76		2.96		6.68	
	nls	Average	2.75	0.1	2.95	0.09	6.79	1.57

Table 6: Comparison of results in CEG (2013b) with fitting the model in R, using average data: Data1, Data2, Data3, and Data4.

The estimates and standard errors in Table 6 depend on assumptions that the data is Normally distributed with the same variance. To check the Normality assumption, QQ (Quantile-Quantile) plots are given in Figure 5. In the QQ plot, the ordered residuals (observed yields minus fitted values) are plotted on the y-axis, while expected values from a standard Normal distribution are plotted on the x-axis. If the residuals follow a Normal distribution, then the QQ plot should follow an approximate straight line. Deviations from the line correspond to indications of non-Normality or outliers. All of the QQ plots are approximately straight and have two possible outliers. The low outlier is a bond issued by AMP Group Finance Services, while the high outlier is a bond issued by Commonwealth Property Office Fund[6].

Figure 6 shows the data and the fitted curve with 95% confidence limits based on ±1.96 standard errors. The confidence intervals are quite narrow.

3.6 Opinion

The results show good agreement with those given by CEG in CEG (2013b). We agree with CEG in the value of using curve fitting to estimate the debt risk premium at 10 years. The calculation of standard errors is a necessary and useful addition to the fitted curves. The standard errors for the debt risk premiums at 7 and 10 years are relatively small, and the estimates can therefore be used with confidence.

[5]In one dimension, $\text{Var}(g(x)) \approx [g'(\mu)]^2\text{Var}(x)$; In higher dimensions $\text{Var}(g(x)) \approx d'\Sigma d$ where Σ is the variance-covariance matrix of x and d is the vector of first derivatives of g evaluated at μ, implemented in the `delta.method` command in the package `alr3`

[6]The Bloomberg identifiers for the outlying bonds are EC165697 and EI060572 respectively.

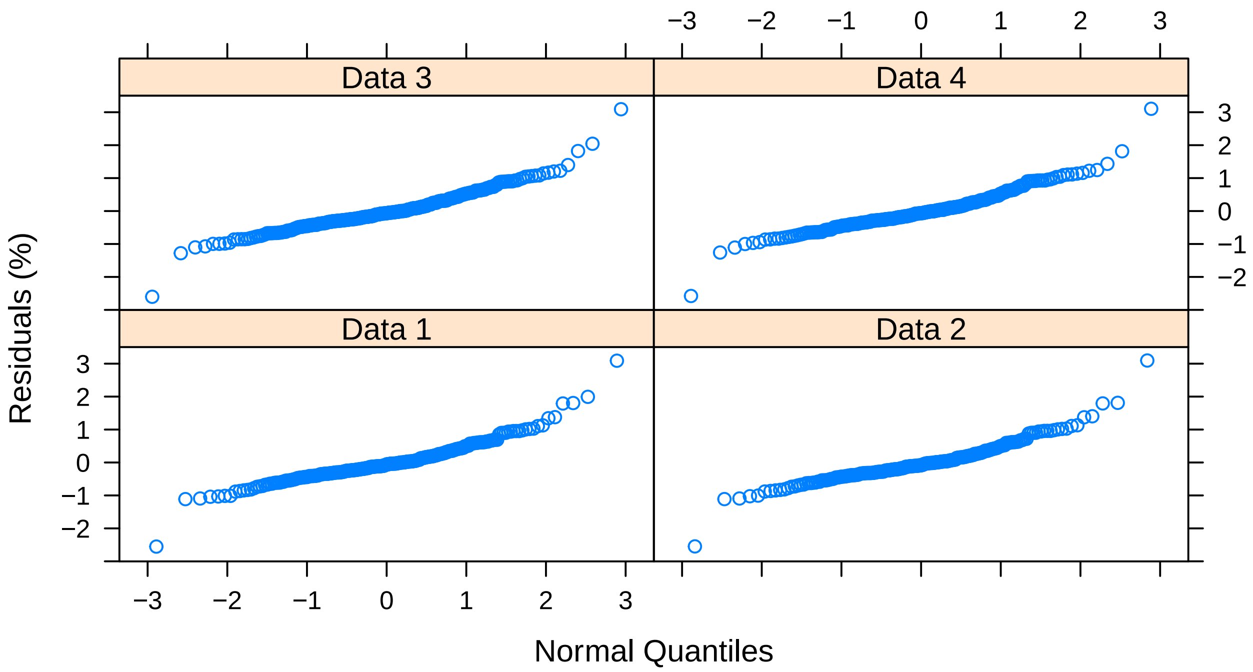

Figure 5: QQ plots of residuals from the Nelson-Siegel model fitted to Data1, Data2, Data3, and Data4.

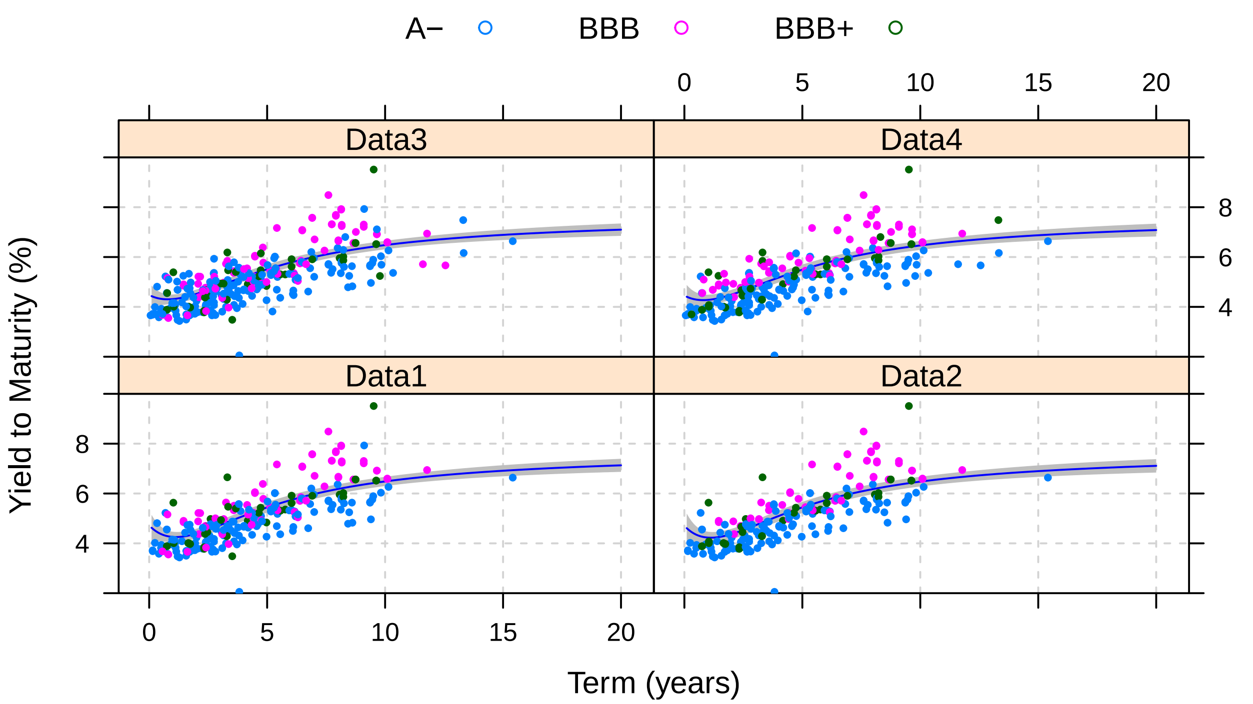

Figure 6: Scatter plots of yield to maturity vs. term, with fitted Nelson-Siegel curves for Data1, Data2, Data3, and Data4 with 95% pointwise confidence intervals, based on average values of bond yields over the reference period (February 2013).

4 Refinements to the analysis

In the second stage of the project, we have:

- Repeated the analysis using robust regression methods in order to mitigate the effects of outliers.
- Examined whether the day-to-day results are stable and developed a method to combine them, both to provide a best estimate of average behaviour and also to assess the precision of the estimated curve.
- Tested whether the parameters are common for bonds in different credit rating bands.
- Examined the effects of weighting for par yield curves.
- Based on this empirical work, given an opinion on the costs of debt that have been determined as par value yields.

4.1 Robust analysis

Irrespective of whether Excel Solver was used or `nls` in R, both have the same objective function. As noted by Fox (2008, p. 463), the general nonlinear model is given by the equation:

$$Y_i = f(\beta, x_i^T) + \varepsilon_i$$

in which

- Y_i is the response-variable value for the ith of n observations;
- β is a vector of p parameters to be estimated from the data;
- x_i^T is a row vector of scores for observation i on the k explanatory variables (some of which may be qualitative); and
- ε_i is the error for the ith observation.

Under the assumption of independent and normally distributed errors, with zero means and common variance, the general nonlinear model has likelihood

$$\begin{aligned} L(\beta, \sigma_\varepsilon^2) &= \frac{1}{2\pi\sigma_\varepsilon^2} \exp\left\{ -\frac{\sum_{i=1}^n [Y_i - f(\beta, x_i^T)]^2}{2\sigma_\varepsilon^2} \right\} \\ &= \frac{1}{2\pi\sigma_\varepsilon^2} \exp\left\{ -\frac{1}{2\sigma_\varepsilon^2} S(\beta) \right\} \end{aligned}$$

where $S(\beta)$ is the sum of squares function

$$S(\beta) = \sum_{i=1}^{n} [Y_i - f(\beta, x_i^T)]^2]$$

As for the general linear model, we therefore maximise the likelihood by minimising the sum of squared errors $S(\beta)$.

The above indicates that if the errors are Normally distributed then Least Squares corresponds to Maximum Likelihood estimation. It is also true that if the errors are not Normally distributed, then the Least Squares estimates are consistent, that is as the sample size increases the estimates get closer and closer to the "true" values of the parameters.

There are some outliers in the bond database compiled by CEG. To investigate whether the results depend on only a few observations, the analysis was repeated using a robust non-linear regression method in R, `nlrob`, which uses robust M-estimates, and applies iteratively re-weighted least squares to estimate the fitted model.

The name M-estimate derives from 'MLE-like' estimators (Venables and Ripley, 2008, p.122). Consider the case where only a mean μ is to be estimated and it is known that the standard deviation is 1. Assume that the density of the data is f and $\rho = -\log f$. The MLE solves

$$\min_\mu \sum_i -\log f(y_i - \mu) = \min_\mu \sum_i \rho(y_i - \mu)$$

Let $\psi = \rho'$, the derivative with respect to μ. Then the MLE can be found by using the equations

$$\sum_i \psi(y_i - \mu) = 0 \text{ or } \sum_i w_i(y_i - \mu) = 0$$

where

$$w_i = \frac{\psi(y_i - \hat{\mu})}{y_i - \hat{\mu}}.$$

The estimate of μ is solved iteratively, with the weights being updated at each iteration. The mean corresponds to $\rho(x) = x^2$. In this case $\psi(x) = 2x$. The idea of a robust M-estimator is to choose a different function for ψ where outliers have less of an effect. A popular choice is metric Winsorizing with

$$\psi(x) = \begin{cases} -c & x < -c \\ x & |x| < c \\ c & x > c \end{cases}$$

shown in Figure 7. Here the effects of outliers are trimmed to $\pm c$. The results depend on the choice of c. By choosing $c = 1.345$, it can be shown that the relative efficiency of the robust M-estimator relative to least squares is 95%.[7]

The standard deviation is never known and so a robust estimator is needed. The choice used in the `nlrob` package is the MAD (Median Absolute Deviation) estimator given by the median of the absolute values of the deviations from the mean, divided by 0.6475.

Extensions of the robust M-estimator methodology to multiple linear regression and non-linear estimation follow a similar logic.

The reparameterised Nelson-Siegel model was fitted to the Data1, Data2, Data3, and Data4 data sets, using `nlrob`. Estimates of the DRP_7, DRP_{10}, and ΔDRP were found by substituting the parameter estimates into the relevant formula. Standard errors were found using the delta method and are given in Table 7, with comparisons to the estimates in the report, CEG (2013b), and those using `nls`.

Table 7 shows that, following the application of the robust regression method to yield curves estimated across the four data sub-samples, the estimates of the DRP at 7 years and at 10 years are brought down. The DRP_7 is reduced by between 0.10% to 0.13%, while DRP_{10} is reduced by between 0.12% to 0.13%. The standard errors of the estimates of DRP_7 and DRP_{10} remain consistently low, and in fact fall further in a few instances. The increment to the debt risk premium, from 7 to 10 years, diminishes by very small amounts of less than one basis point per annum. Thus, for Data3, ΔDRP diminishes marginally from 6.78 bppa to 6.43 bppa. Figure 8 provides scatter plots of the data and also shows the fitted curve with confidence intervals for each of the four datasets.

[7] The variance of the least squares estimator is 95% of the variance of the robust M-estimator if there were no outliers.

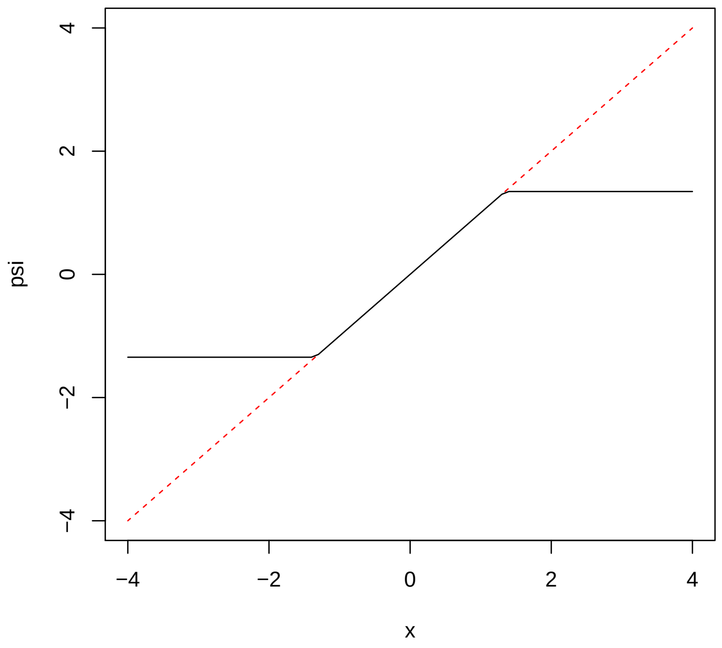

Figure 7: ψ function for Robust regression (solid) and for normal regression (dotted)

			DRP_7		DRP_{10}		ΔDRP	
			Estimate	Std.err	Estimate	Std.err	Estimate	Std.err
Data Set	Source	Data	(%)	(%)	(%)	(%)	(bppa)	(bppa)
Data1	Report	Individual	2.76		2.99		7.62	
	optim	Individual	2.76		2.99		7.59	
	nls	Average	2.73	0.1	2.97	0.09	7.8	1.63
	nlrob	Average	2.63	0.09	2.85	0.09	7.54	1.47
Data2	Report	Individual	2.76		2.99		7.38	
	optim	Individual	2.76		2.98		7.35	
	nls	Average	2.73	0.11	2.96	0.1	7.58	1.72
	nlrob	Average	2.6	0.1	2.83	0.09	7.51	1.52
Data3	Report	Individual	2.78		2.98		6.67	
	optim	Individual	2.77		2.97		6.64	
	nls	Average	2.76	0.09	2.96	0.09	6.78	1.49
	nlrob	Average	2.65	0.09	2.85	0.09	6.43	1.45
Data4	Report	Individual	2.76		2.96		6.71	
	optim	Individual	2.76		2.96		6.68	
	nls	Average	2.75	0.1	2.95	0.09	6.79	1.57
	nlrob	Average	2.63	0.09	2.83	0.09	6.72	1.44

Table 7: Comparison of results in CEG (2013b) with fitting the model in R, using average data with `nlrob`: Data1, Data2, Data3, and Data4. The reference to average data means daily observations that have been averaged over the reference period of February 2013.

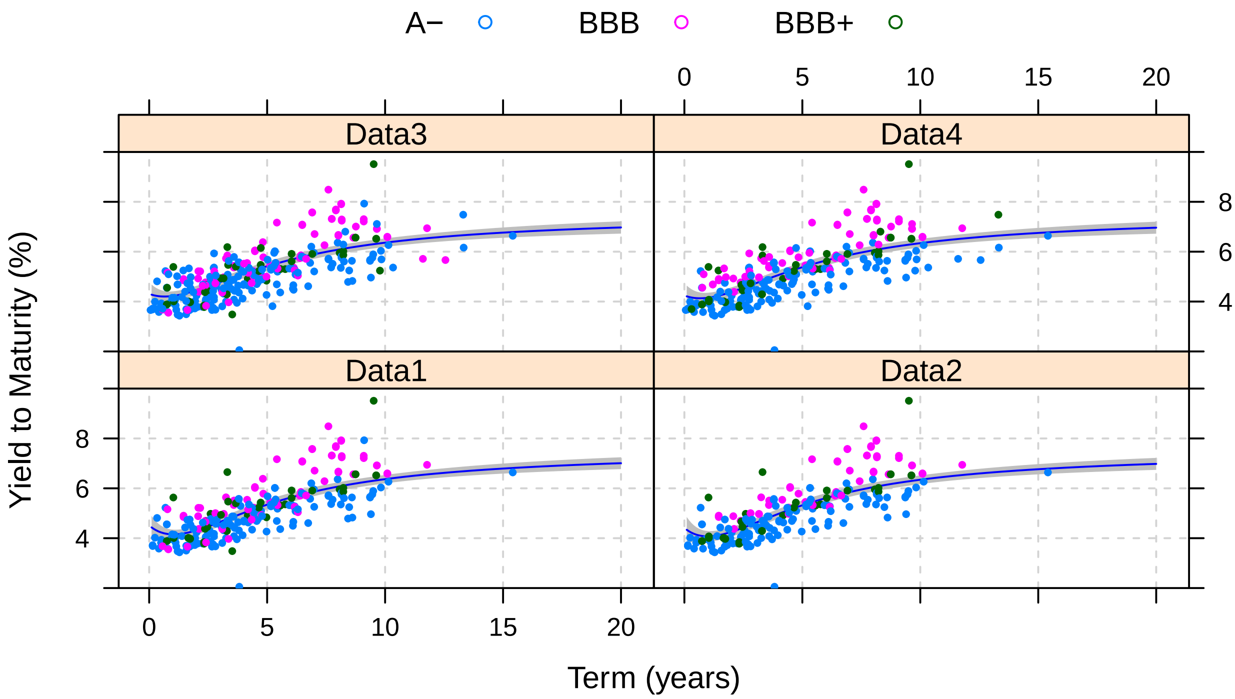

Figure 8: Scatter plots of yield to maturity vs. term, with fitted Nelson-Siegel curve for Data1, Data2, Data3, and Data4 with 95% pointwise confidence intervals, based on average values using `nlrob`.

4.2 Analysis of daily results

In section 3 and in section 4.1, a monthly average of the daily yields was used. In this section, the data is analysed day by day, to assess the stability of the results. In addition, methods for combining the daily results are developed and applied to datasets 1 to 4.

The analysis was carried out on the daily bond yield data, and the results were converted into estimates of the debt risk premium by subtracting, from bond yields, the applicable daily yields on CGS with a corresponding term to maturity. The yields on CGS for a particular term to maturity were calculated by interpolating between the observations for particular Commonwealth Government bonds in relation to which the maturity dates straddled the target maturity date.

For each day, the reparameterised Nelson-Siegel model was fitted to the data using `nls`. Standard errors were calculated using the Delta method. The Daily results for DRP_{10} with 95% confidence intervals calculated as $\pm$ 1.96 standard errors are presented in Figure 9. Note that Day 12 was a public holiday in the USA and there is no data for almost a third of the bonds[8]. Figure 9 shows that the results from day to day are quite autocorrelated but relatively stable. Corresponding figures for DRP_7 and $\Delta(DRP)$ are shown in Figures 10 and 11. DRP_7 behaves similarly to DRP_{10}, but ΔDRP is less correlated.

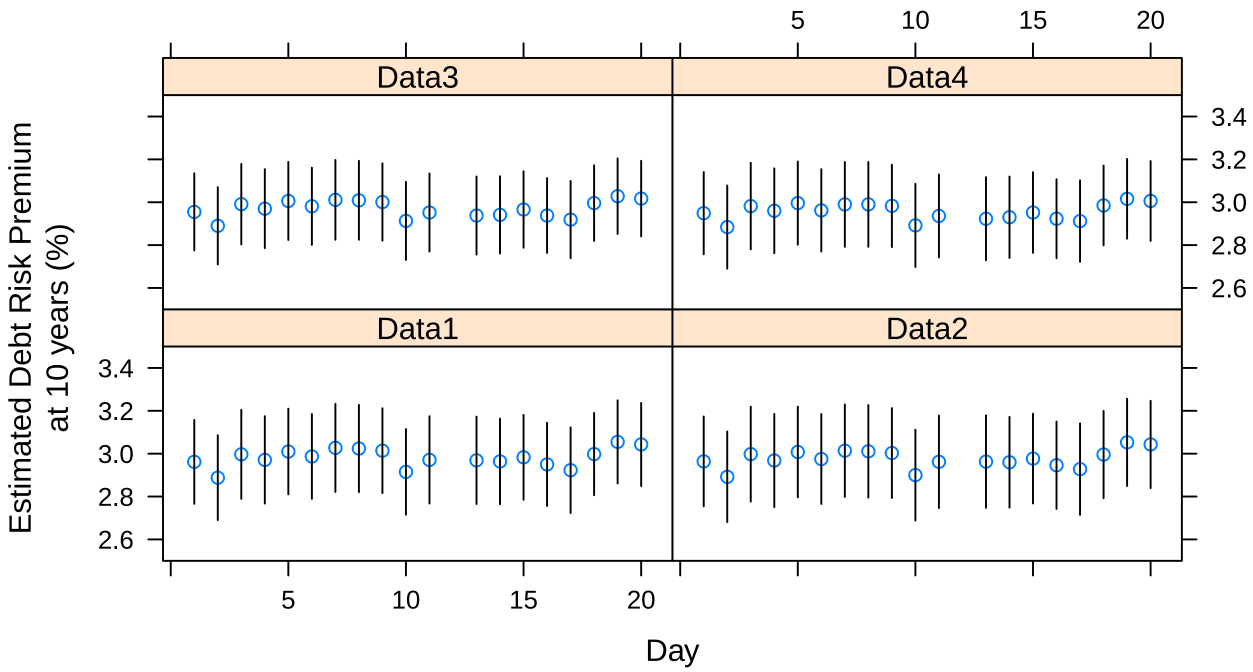

Figure 9: Estimated debt risk premiums at 10 Years, with 95% confidence intervals by day: Data1, Data2, Data3, Data4.

Figures 9, 10, and 11 show that, apart from one day, the day-to-day results are stable. There is some autocorrelation from day to day, and correlation of the daily results for individual bonds is to be expected. A suitable model for the daily results is a non-linear mixed effects model (see, for example, Pinheiro and Bates, 1988), which for the jth observation for the ith bond can be written as

$$\text{Yield}_{i,j}(t, \text{rank}) = \beta_{1,\text{rank}} + b_i + (\beta_2 + \beta_3)\frac{1 - \exp(-t/\beta_0)}{t/\beta_0} - \beta_3 \exp(-t/\beta_0) + \varepsilon_{i,j} \tag{2}$$

where b_i is a random effect for bond i, assumed to be Normally distributed with zero mean, and the errors $\varepsilon_{i,j}$ are also assumed to be Normally distributed and independent from bond to bond but

[8] Day 12 corresponds to 18th February 2013.

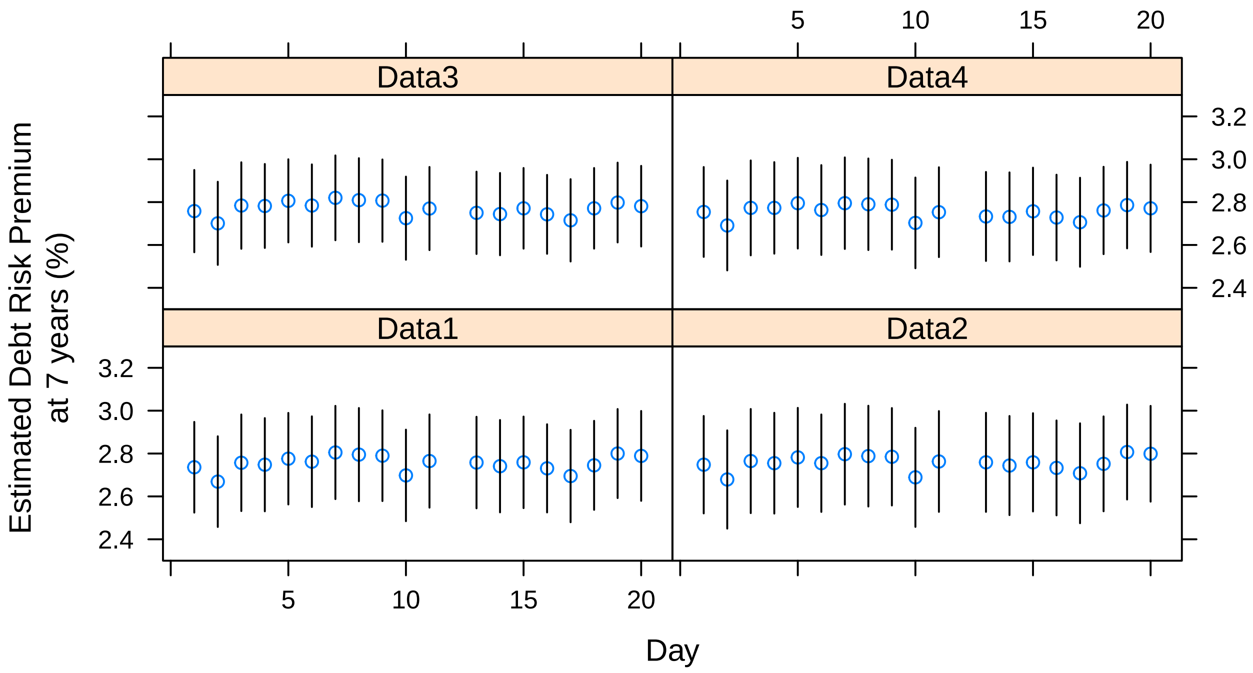

Figure 10: Estimated debt risk premiums at 7 Years, with 95% confidence intervals by day: Data1, Data2, Data3, Data4.

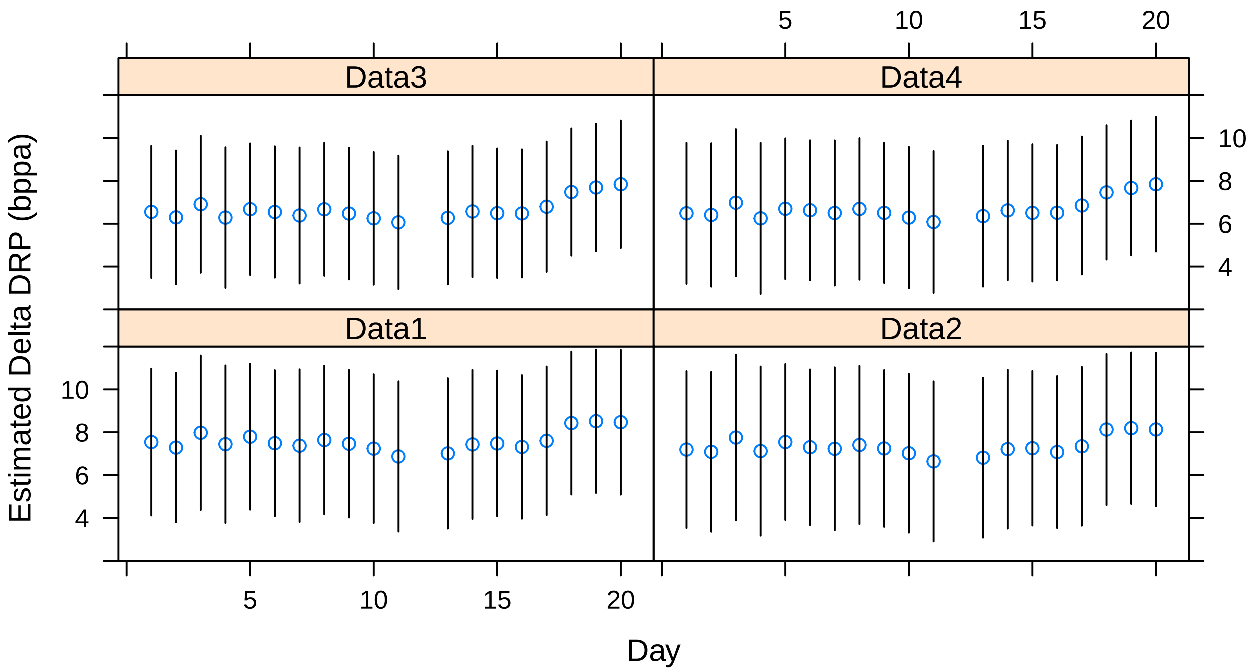

Figure 11: Estimated Delta debt risk premiums, with 95% confidence intervals by day: Data1, Data2, Data3, Data4.

with serial correlation within a bond[9]. The model was fitted to the four data sets using the `nlme` package in R. The autocorrelation of the within-bond data was estimated to be above 0.8 for all data

[9]The day to day variation was modelled as an AR(1) model (see, for example, Box, Jenkins, and Reinsel (1994)). The AR(2) model was also fitted but the additional parameter was not statistically significant.

sets. QQ plots of the bond random effects and residuals are given in Figure 12. The QQ plot of the residuals suggests that the residuals are well-behaved and correspond to a Normal distribution. The values of the random effects parameter for each bond are also well-behaved and correspond to a Normal distribution, with the possibility of two outliers.

The use of a mixed model specification allows the focus to be on the fixed effects, representing the average yield for a bond of a particular maturity, rather than the yields for particular bonds. The analysis provides a convenient way to take into account the correlation of the results for each bond, as well as modelling the day to day dependence. The random effects parameter, b_i, captures the idiosyncracies associated with each bond.

Table 8 gives the estimates and standard errors of DRP_7, DRP_{10} and ΔDRP for the four data sets with comparisons to the results in CEG (2013b) and with using `nls` and `nlrob`.

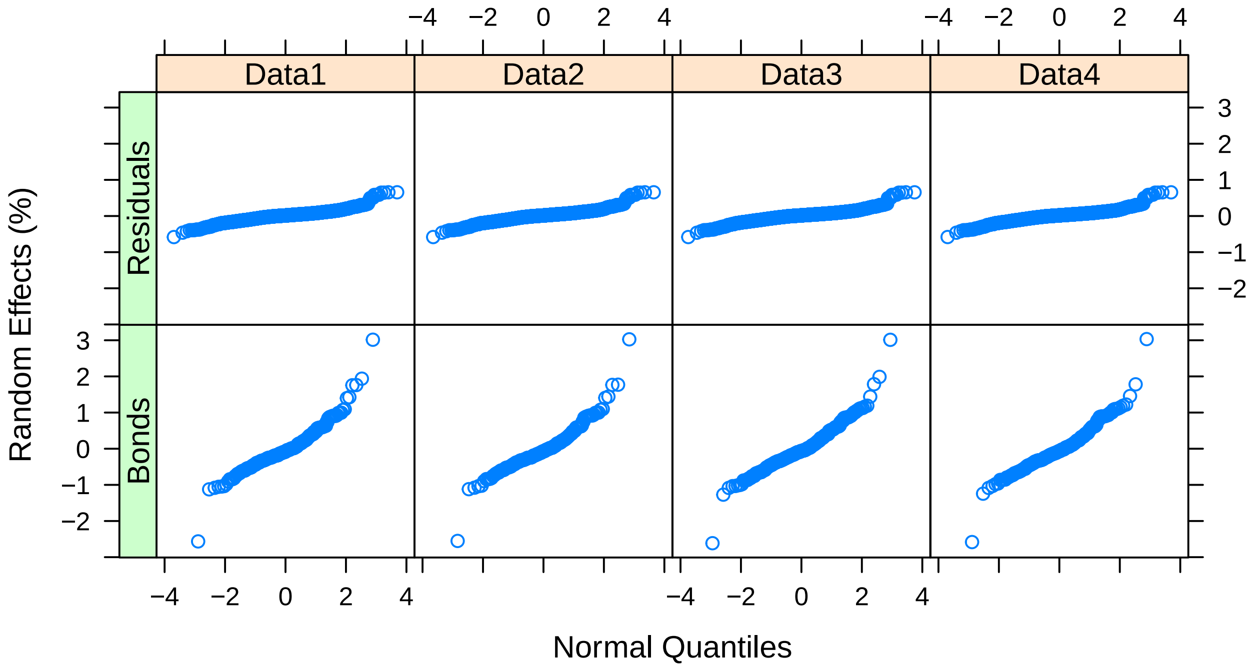

Figure 12: QQ plots of bond random effects and of residuals based on a non-linear mixed effects model: Data1, Data2, Data3, Data4. Recall that the bond random effects parameter, b_i has a mean of zero. The y-axis shows the deviations of this parameter from zero. The other y-axis shows the distribution of the regression residuals. The bond random effect is to be interpreted relative to the average yield, so that if the average yield at a certain term to maturity is 6.5% and a bond random effect is 1.0%, then the average yield for that bond is 7.5%.

			DRP_7		DRP_{10}		ΔDRP	
			Estimate	Std.err	Estimate	Std.err	(bppa)	Std.err
Data Set	Source	Data	(%)	(%)	(%)	(%)	(bppa)	(bppa)
Data1	Report	Individual	2.76		2.99		7.62	
	optim	Individual	2.76		2.99		7.59	
	nls	Average	2.73	0.1	2.97	0.09	7.8	1.63
	nlrob	Average	2.63	0.09	2.85	0.09	7.54	1.47
	nlme	Individual	2.74	0.1	2.99	0.09	8.31	1.58
Data2	Report	Individual	2.76		2.99		7.38	
	optim	Individual	2.76		2.98		7.35	
	nls	Average	2.73	0.11	2.96	0.1	7.58	1.72
	nlrob	Average	2.6	0.1	2.83	0.09	7.51	1.52
	nlme	Individual	2.73	0.11	2.97	0.1	8.17	1.66
Data3	Report	Individual	2.78		2.98		6.67	
	optim	Individual	2.77		2.97		6.64	
	nls	Average	2.76	0.09	2.96	0.09	6.78	1.49
	nlrob	Average	2.65	0.09	2.85	0.09	6.43	1.45
	nlme	Individual	2.77	0.09	2.99	0.09	7.13	1.44
Data4	Report	Individual	2.76		2.96		6.71	
	optim	Individual	2.76		2.96		6.68	
	nls	Average	2.75	0.1	2.95	0.09	6.79	1.57
	nlrob	Average	2.63	0.09	2.83	0.09	6.72	1.44
	nlme	Individual	2.75	0.1	2.97	0.09	7.22	1.52

Table 8: Comparison of results in CEG (2013b) with fitting the model in R, using daily data with `nlme`: Data1, Data2, Data3, and Data4.

4.3 Are common parameters justified?

The CEG report, CEG (2013c), fits a model where the intercept terms are different for the different classes of bonds, but the parameters β_0 (also β_6), β_2, and β_3 are common. The assumption that the aforementioned parameters take on the same values for each of the three classes of bonds can be regarded as a restriction. In this section, models where the restriction is relaxed are fitted, and tests are applied to ascertain whether there are statistically significant differences between the restricted and unrestricted versions of the model.

The Nelson-Siegel model, used by CEG, can be written as

$$\begin{aligned}\text{Yield}(t, \text{rank}) &= \beta_{1,\text{rank}} + (\beta_2 + \beta_3)\frac{1 - \exp(-t/\beta_0)}{t/\beta_0} - \beta_3 \exp(-t/\beta_0) \\ &= \beta_1 + (\beta_2 + \beta_3)\frac{1 - \exp(-t/\beta_0)}{t/\beta_0} - \beta_3 \exp(-t/\beta_0) + \beta_4\text{A-} + \beta_5\text{BBB}\end{aligned}$$

where A- and BBB are dummy variables for A- and BBB bonds respectively. An extended model which allows all the parameters to vary is given by

$$\text{Yield}(t, \text{rank}) = \beta_1^* + (\beta_2^* + \beta_3^*)\frac{1 - \exp(-t/\beta_0^*)}{t/\beta_0^*} - \beta_3 \exp(-t/\beta_0^*) \tag{3}$$

where

$$\begin{aligned}\beta_0^* &= \beta_0 + \beta_7\text{A-} + \beta_8\text{BBB} \\ \beta_1^* &= \beta_1 + \beta_4\text{A-} + \beta_5\text{BBB} \\ \beta_2^* &= \beta_2 + \beta_9\text{A-} + \beta_{10}\text{BBB} \\ \beta_3^* &= \beta_3 + \beta_{11}\text{A-} + \beta_{12}\text{BBB}\end{aligned} \tag{4}$$

where β_7 and β_8 are deviations of the β_0 parameter for A$-$ and BBB bonds, respectively; while β_9 and β_{10} are corresponding deviations of the β_2 parameter, and β_{11} and β_{12} are corresponding deviations for the β_3 parameter.

The extended model was fitted to each of the four datasets, using `nls` and the averaged data. Figure 14 shows the fitted curves for both the common coefficient case and the varying coefficient case for the four datasets. While in some cases the curves based on varying coefficients appear to be different in appearance, in no cases do the curves cross: The A$-$ curve is always below the BBB+ curve, which, in turn, is always below the BBB curve.

To test whether the varying curve is justified, a hypothesis test was performed to investigate whether the parameters $\beta_7, \ldots, \beta_{12}$ are significantly different to zero. This was done using Analysis of Variance where the common and extended models were fitted to the data and the change in the residual sum of squares was compared to the residual mean square of the extended model.

In the F-test carried out here, the test statistic is calculated as

$$F = \frac{(\text{RSS Common} - \text{RSS Varying})/g}{(\text{RSS Varying})/(n-k)}$$

where

$$\begin{aligned}\text{RSS Common} &= \text{residual sum of squares with common coefficients} \\ \text{RSS Varying} &= \text{residual sum of squares with varying coefficients} \\ g &= \text{the number of extra parameters} \\ n &= \text{the number of data points} \\ k &= \text{the number of parameters in the model with varying coefficients}\end{aligned}$$

The null hypothesis is that the restriction is valid and that all of the additional parameters are equal to zero. Under the null hypothesis, the F statistic has a known distribution and a $p-$value can be calculated, with large values of F and corresponding small values of p indicating that the additional parameters may be required.

The results of the tests for the four models are given in Table 9. In all cases, the null hypothesis could not be rejected at the 5% level, although the result was close for Data4.

Despite the non-significance of the extra parameters in the extended model, Table 10 gives the estimated DRPs and ΔDRP for Data1, Data2, Data3, and Data4, for both the model with common parameters and the model with varying parameters. The standard errors are higher with the extended model. The Debt Risk Premiums are also higher at both 7 and 10 years, while the ΔDRPs are lower for Data1 and Data2 but higher for Data3 and Data4.

Data Set	RSS Common	RSS Varying	Δ RSS	F	df1	df2	$p-$value
1	82.404	79.474	2.930	1.524	6	248	0.171
2	72.087	68.691	3.397	1.722	6	209	0.117
3	95.766	92.273	3.493	1.861	6	295	0.087
4	83.023	79.037	3.987	2.068	6	252	0.056

Table 9: Anova for comparing the model with common β_6, β_2, and β_3 parameters with the model where these parameters are not common: Data1, Data2, Data3, and Data4. Please note that the parameter β_6 represents the re-parameterised version of β_0.

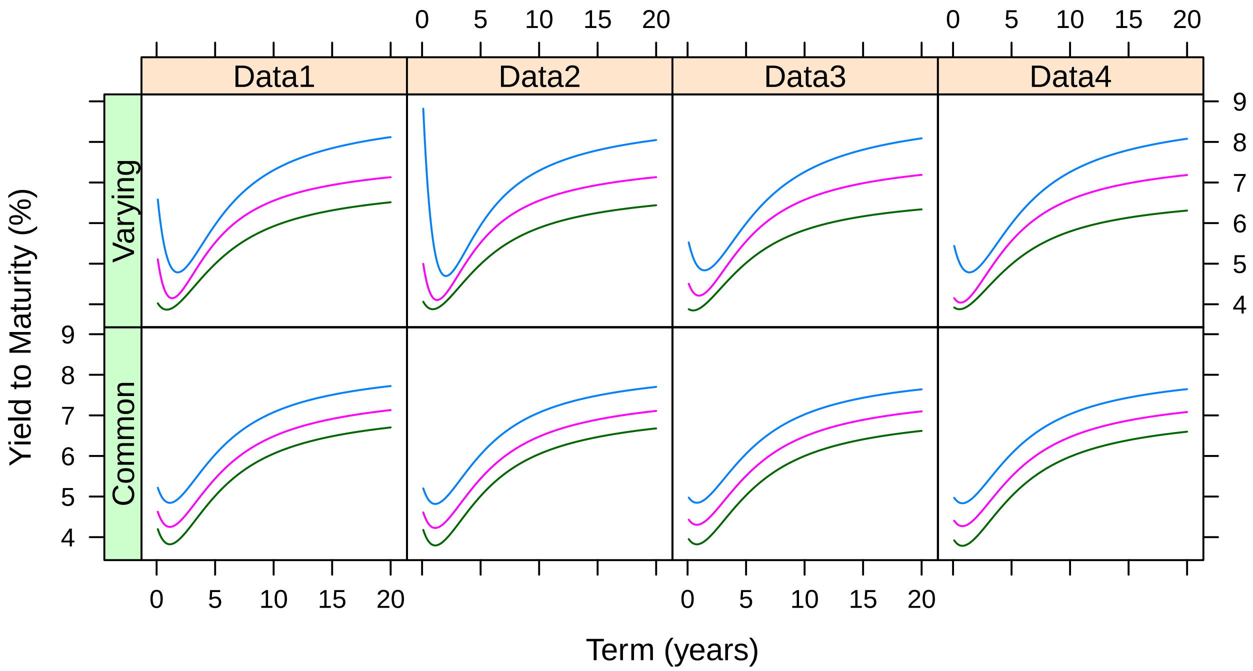

Figure 13: Model fitted by CEG with common and varying β_6, β_2 and β_3 parameters: Data 1, Data2, Data3, and Data4.

		DRP_7		DRP_{10}		ΔDRP	
		Estimate	Std.err	Estimate	Std.err	Estimate	Std.err
Data Set	Parameters	(%)	(%)	(%)	(%)	(bppa)	(bppa)
Data1	Common	2.73	0.1	2.97	0.09	7.8	1.63
	Varying	2.83	0.13	3.04	0.12	6.9	2.51
Data2	Common	2.73	0.11	2.96	0.1	7.58	1.72
	Varying	2.83	0.14	3.04	0.12	6.9	2.51
Data3	Common	2.76	0.09	2.96	0.09	6.78	1.49
	Varying	2.84	0.13	3.06	0.11	7.27	2.3
Data4	Common	2.75	0.1	2.95	0.09	6.79	1.57
	Varying	2.85	0.14	3.06	0.12	7.09	2.36

Table 10: Comparison of DRP_7, DRP_{10}, and ΔDRP for common and varying parameters: Data1, Data2, Data3, Data4.

5 Application of zero coupon Nelson-Siegel yield curves to estimate par yield curves

Nelson and Siegel (1987) provide a model that, while parsimonious, has the ability to generate the shapes typically associated with yield curves. Their model is widely used by central banks either in its original form or in the modified form that Svensson (1994) provides[10]. In this section, we estimate zero-coupon yield curves or spot rate curves that belong to the family of Nelson-Siegel curves. Subsequently, we use these estimates to generate estimates of par yield curves. Schaefer (1977) shows how one can uncover the term structure of par yields from the term structure of spot rates.

The approach that we use is to search for a term structure of spot rates that will minimise an objective function that is a weighted average of the squared differences between the actual prices of a range of bonds and the prices of those bonds that the term structure of spot rates indicates should prevail. The actual bond prices that we use are the so-called 'dirty' prices. The dirty price of a bond, P_i^A, is the price that one must pay to buy the bond. The 'clean' price, P_i^C, is, in contrast, the dirty price less an amount representing 'accrued' interest, a_i:

$$P_i^A = P_I^C + a_i$$

i.e.

$$\text{Dirty Price} = \text{Clean Price} + \text{Accrued Interest}$$

The Accrued interest of bond i is given by

$$a_i = \frac{\text{number of days since last coupon payment}}{\text{number of days in current coupon period}} \times C_i$$

where C_i is the next coupon payment to be made for bond i.

The discount rate for a bond with a particular credit rating, designated by "rank" is given by:

$$r(t, \text{rank}) = \beta_{1,\text{rank}} + (\beta_2 + \beta_3)\frac{1 - \exp(-t/\beta_0)}{t/\beta_0} - \beta_3 \exp(-t/\beta_0)$$

where t is the time to the bond's next payment which is discounted at rate $r(t, \text{rank})$. The price of a bond that the term structure of spot rates indicates should prevail is simply the cash flows that the bond will deliver discounted using the term structure. The parameters are estimated by minimising the weighted sum of pricing errors

$$\sum_{i=1}^{N} [w_i(P_i^A - \hat{P}_i)]^2$$

where

$$\begin{aligned} w_i &= \frac{1/d_i}{\sum_{k=1}^{N} 1/d_k} \text{ where } d_i = \text{Macaulay duration of bond } i \\ N &= \text{Number of bonds in the sample} \\ P_i^A &= \text{the actual ``dirty'' price of bond } i \\ \hat{P}_i &= \text{fitted price of bond } i \text{ given by } \hat{P}_i = \sum_t C_{it} \exp\left[-t \times r(t, \text{rank})\right] \end{aligned}$$

where C_{it} is a cash flow on bond i promised to be paid t years from now.

It should be emphasised that the weights, w_i, in the formulation shown above are inside the square brackets and hence are squared. Essentially the parameters are estimated by minimising the quantity

$$\sum_{i=1}^{N} [u_i(P_i^A - \hat{P}_i)^2]$$

[10] See, for example, the discussion in: Bank for International Settlements, Zero-coupon yield curves: Technical documentation, Monetary and Economic Department, October 2005.

where

$$u_i = w_i^2 = \frac{(1/d_i)^2}{(\sum_{k=1}^{N}(1/d_k))^2},$$

giving more weight to bonds with shorter durations. The u_i correspond to the more traditional weights in "weighted least squares". Examination of the literature shows that such a weighting has been used by a number of authors. For example, Ioannidis (2003) says

> I estimate the Nelson and Siegel . . . I choose to minimise the distance between squared price errors weighted by the inverse of the duration of the issue squared. This weight function best adjusts for the differential importance of small price changes at different maturities on estimates of the yield curve. An error in the price of a three-month treasury bill would not have the same impact as the error in the price of a fifteen year bond. If we assume an equal weight, the pricing of long term issues would be less accurate than the pricing of short term maturity issues due to increasing duration. Similar weighting schemes are adopted by Vasicek and Fong (1982) and Bliss (1997).

On the other hand, Ferstl and Hayden (2010) use the inverse of the duration with

$$u_i = \frac{(1/d_i)}{\sum_{k=1}^{N}(1/d_i)}.$$

The parameters were estimated using the `optim` command in `R`, with the BFGS optimisation method. When choosing a subset of data for the estimation of zero coupon yields, an important consideration is that overseas bonds cannot readily be applied, because the empirical work makes use of coupon payments. In other parts of the analysis in this report, overseas bonds have been used, with the yields on foreign currency denominated bonds having been swapped into Australian dollar yields using input data from the cross-currency swaps function that is available through the Bloomberg information service. However, there doesn't seem to be a well-founded basis for applying this method directly to a future stream of coupon payments, and so overseas bonds issued by Australian corporations were ruled out of the analysis.

The data sub-sample used in this section has been described as Data9 because the dataset corresponds to row 9 from Table 4A of CEG (2013b). The bonds that were suitable for application to the current task possessed the following characteristics: The three credit ratings under consideration were represented (A-, BBB+ and BBB), the bonds were denominated in Australian dollars, there was a mix of bonds with and without optionality features, and the yields used were those reported by Bloomberg only. The domicile of the issuer was not restricted to Australia, and the sample was comprised of 117 observations.

We used inverse duration weighting since if we had used squared inverse weighting the bond with the shortest maturity would have received between 25% to over 41% (depending on which day of the reference period is in question) of the weight. Figure 14 gives the spot rate curves for each day, while Figure 15 gives the average spot curve over the reference period.

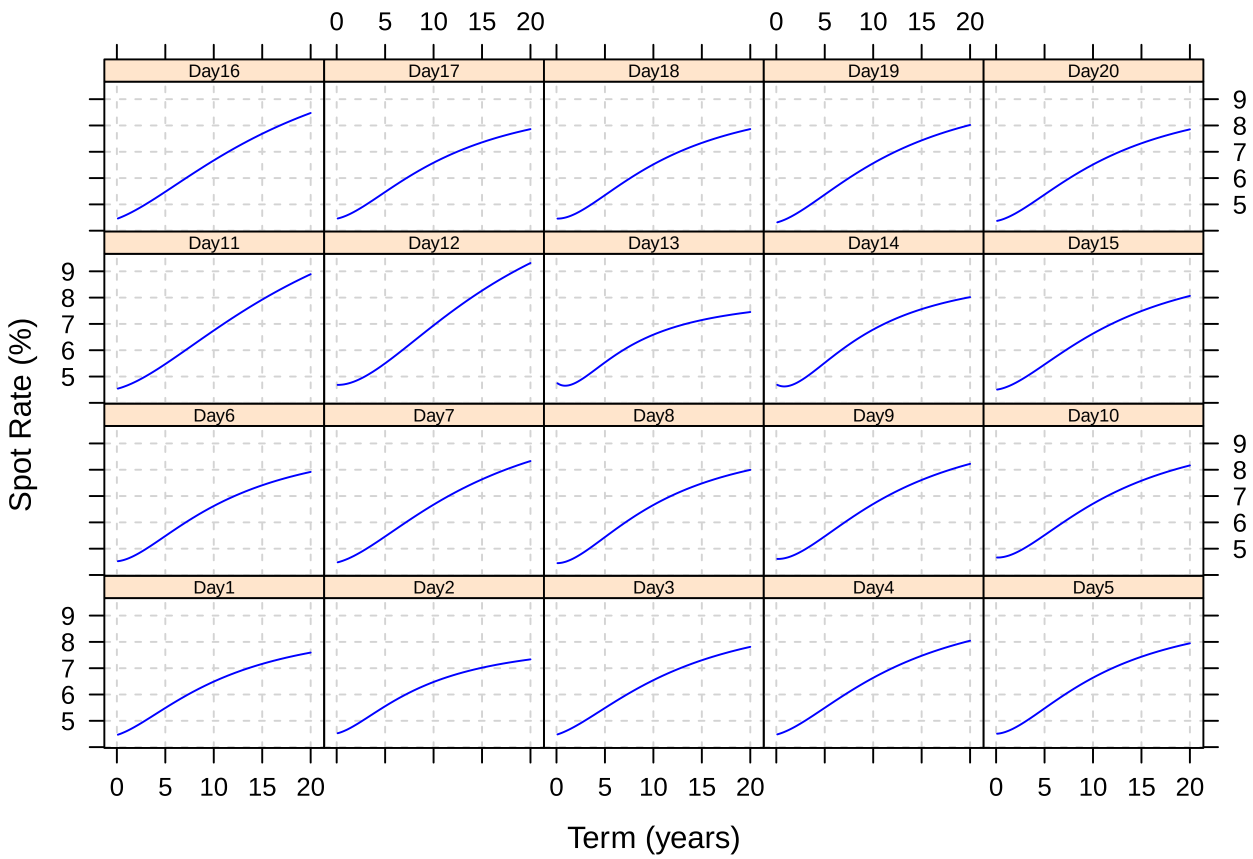

Figure 14: Spot rate curves for Data9 with inverse duration weighting.

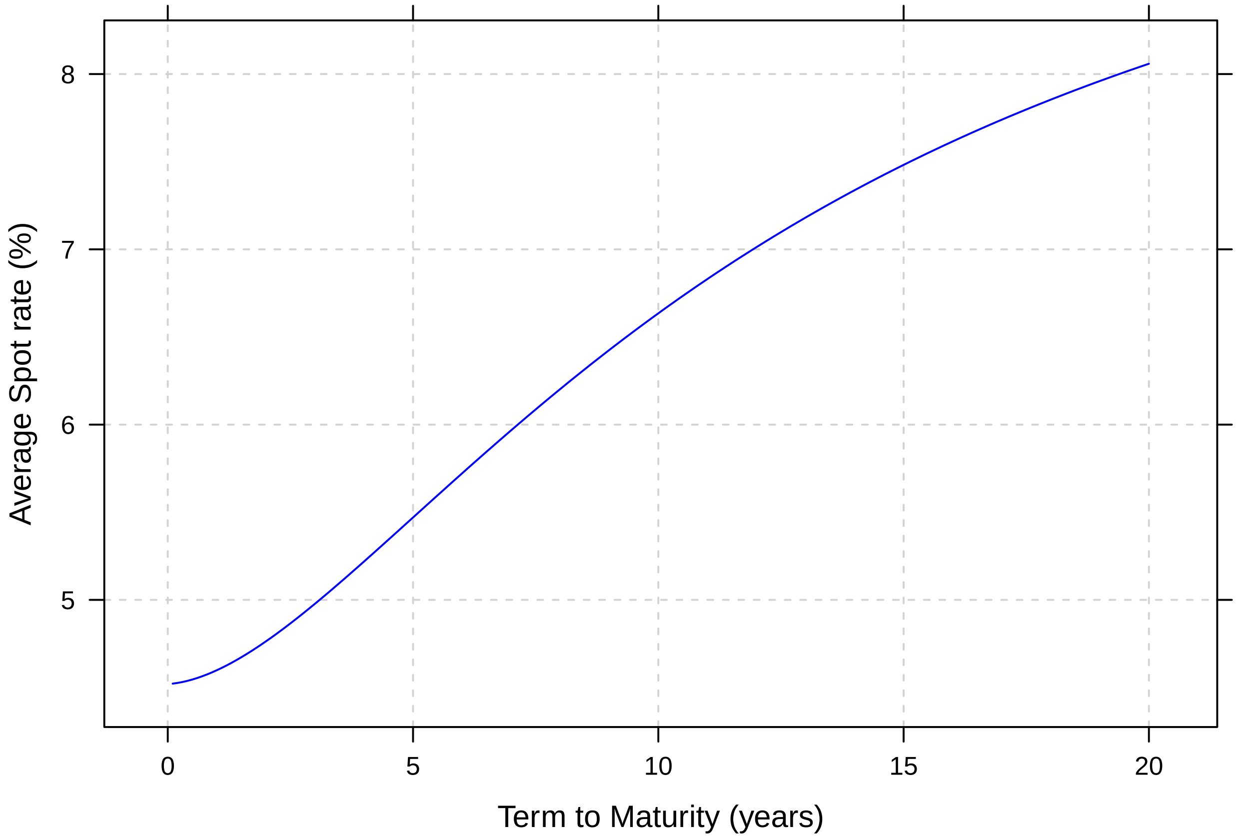

Figure 15: Average spot rate curve for Data9 with inverse duration weighting.

Once the parameters are estimated, the par yield, which is the coupon rate C that causes the bond price to equal its par value, can be calculated. Assuming semi-annual coupon payments for bond maturity T, the equation is

$$100 = \frac{C}{2}\exp\left[-0.5r_{0.5}\right] + \frac{C}{2}\exp\left[-r_1\right] + \ldots + (100 + \frac{C}{2})\exp\left[-Tr_T\right].$$

In the report Solver was used to solve for C but the following equation can be used:

$$C = \frac{200(1 - \exp\left[-Tr_T\right])}{\sum_{t=1}^{2T}\exp\left[-\frac{t}{2}r_{\frac{t}{2}}\right]}$$

Figure 16 gives the par value curve for each day while Figure 17 gives the average par yield curve over the reference period. See also Table 11. At 10 years the par yield is 6.49% and hence the debt risk premium is 2.98% (the yield minus the average value of the risk-free rate over the month).

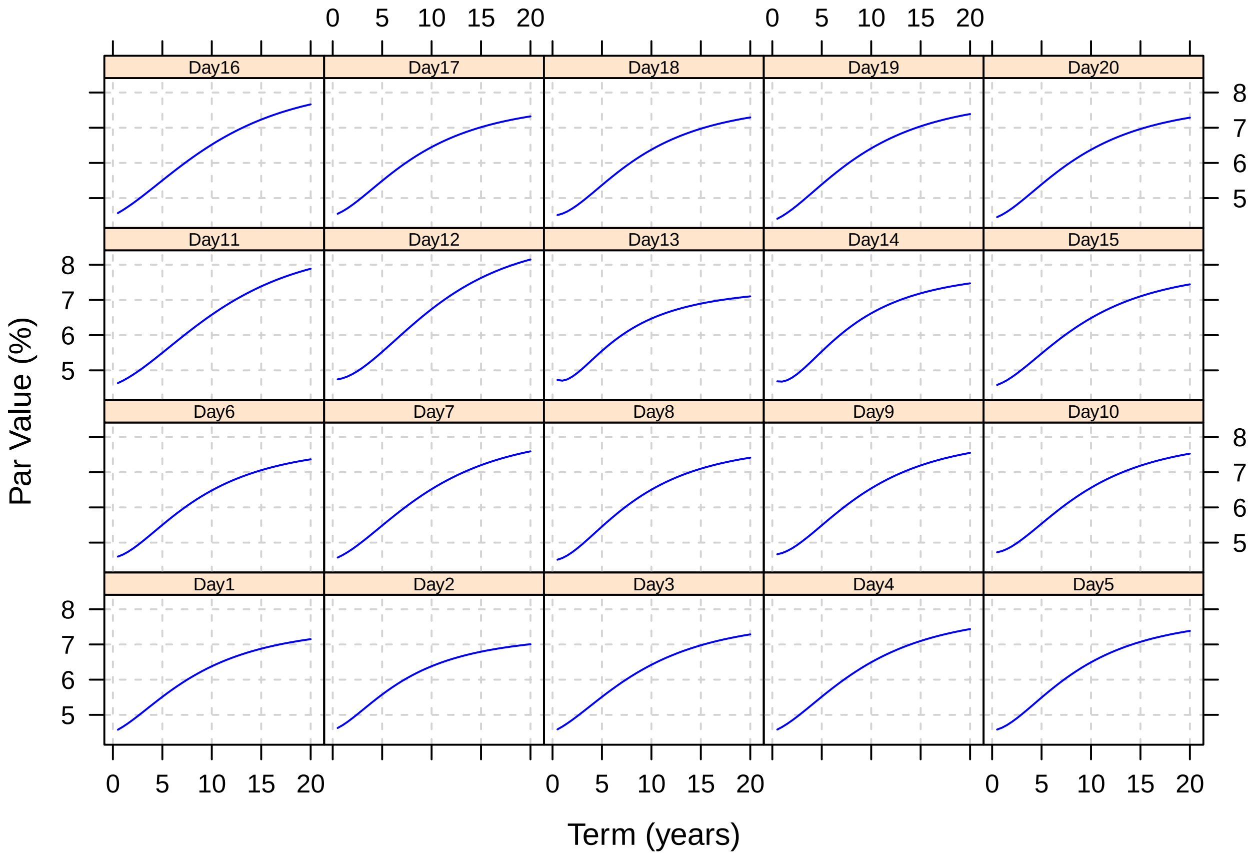

Figure 16: Par value curves by day

Alternatively, annual coupon payments could be assumed. For bond maturity T, the equation is

$$100 = C\exp\left[-r_1\right] + C\exp\left[-2r_2\right] + \ldots + (100 + C)\exp\left[-Tr_T\right].$$

and therefore

$$C = \frac{100(1 - \exp\left[-Tr_T\right])}{\sum_{t=1}^{T}\exp\left[-tr_t\right]}$$

However, an assumption of annual coupon payments was not made on this occasion.

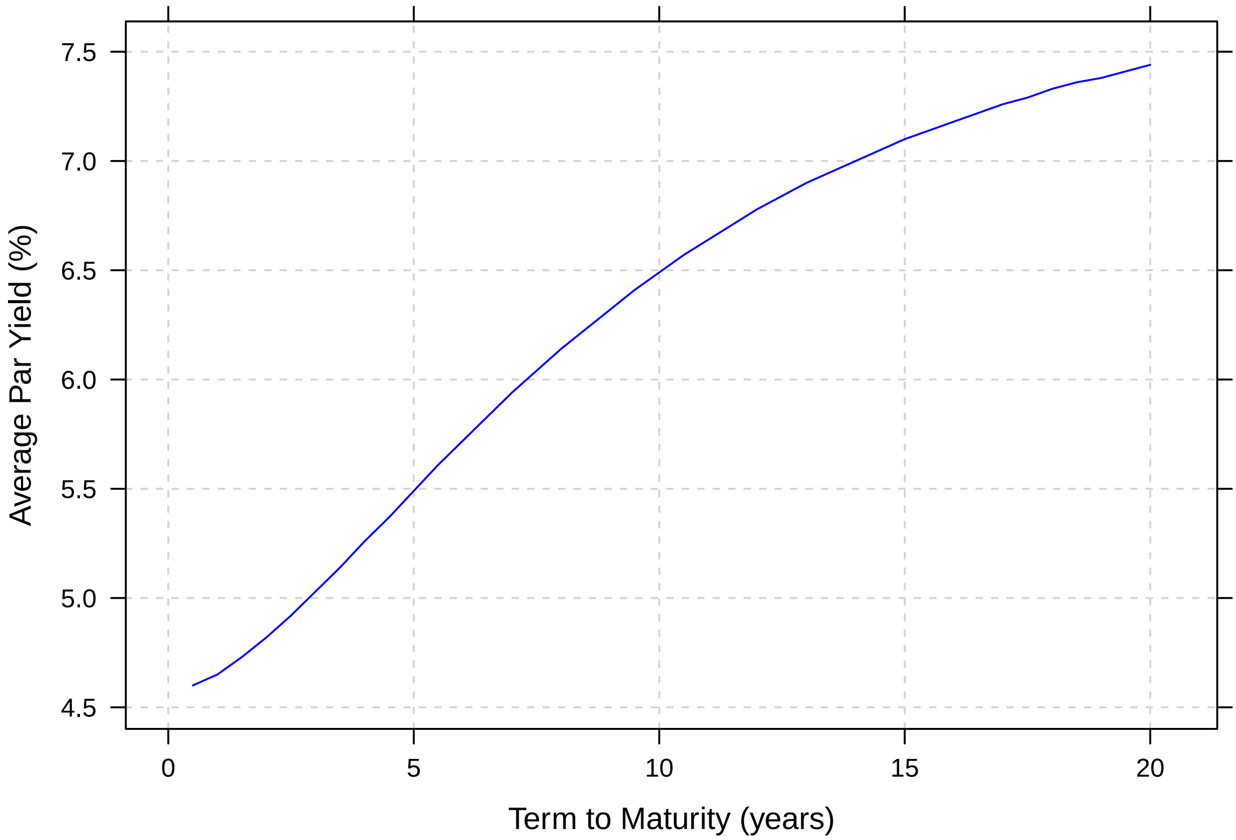

Figure 17: Average par yield curve for Data9 with inverse duration weighting.

Term to Maturity (Years)	Par Value (%)
0.5	4.60
1.0	4.65
1.5	4.73
2.0	4.82
2.5	4.92
3.0	5.03
3.5	5.14
4.0	5.26
4.5	5.37
5.0	5.49
5.5	5.61
6.0	5.72
6.5	5.83
7.0	5.94
7.5	6.04
8.0	6.14
8.5	6.23
9.0	6.32
9.5	6.41
10.0	6.49
10.5	6.57
11.0	6.64
11.5	6.71
12.0	6.78
12.5	6.84
13.0	6.90
13.5	6.95
14.0	7.00
14.5	7.05
15.0	7.10

Table 11: Par value yields (%) developed from the spot rate curve

6 Comparison of results from yield curves with those obtained using the methods applied separately by the AER and the Economic Regulation Authority (WA)

In the final stage of the project, we have:

- Examined, using simulation and analysis, the properties of the estimate of the DRP based on simple averaging, as previously proposed by the AER, and the (weighted) bond yield approach developed by the ERA (WA).
- Provided an opinion of the validity of these approaches compared to using methods based on yield curves.

6.1 DRP based on simple averaging

In its draft decision for Aurora, the AER estimated the debt risk premium for a benchmark, 10 year corporate bond by calculating an arithmetic average of the yields on a set of nine bonds[11]. To determine the statistical properties of this method, a simulation exercise was carried out. Nine bonds were sampled with maturities uniformly distributed between 7 and 13 years. For each sampled bond, the yield was calculated using the fitted curve for Data2, and converted to a DRP using an interpolation formula supplied by CEG based on CGS yields. The average DRP was then calculated by taking the arithmetic mean of the results for the predicted yield less the risk free rate, across the nine bonds. The outcomes under the "AER method" thus described were compared with the estimated DRP from a previous Nelson-Siegel curve estimation. The particular result that was presented for comparison was the estimated DRP of 2.96% reported in Table 6. We performed 10,000 simulations. Figure 18 shows the histogram of the averages, clearly showing the bias of the simple averaging method for estimating the DRP for a 10 year term to maturity.

It is not surpising that the DRP, calculated as an arithmetic average, is negatively biased in this case. Jensen's inequality (see, for example, Royden, 1968, p. 110) says that when a function f is concave, then

$$E(f(x)) \leq f(E(x)).$$

The reverse applies when the function f is convex. Over the range of 7 to 13 years maturity, the fitted yield to maturity curve for Data2 is concave, and hence the average DRP from a bond sample will be less than the DRP at the average term to maturity.

[11] AER (2011), Draft Distribution Determination, Aurora Energy Pty Ltd, 2012-2013 to 2016-2017, Australian Energy Regulator, Table 9.7, page 241.

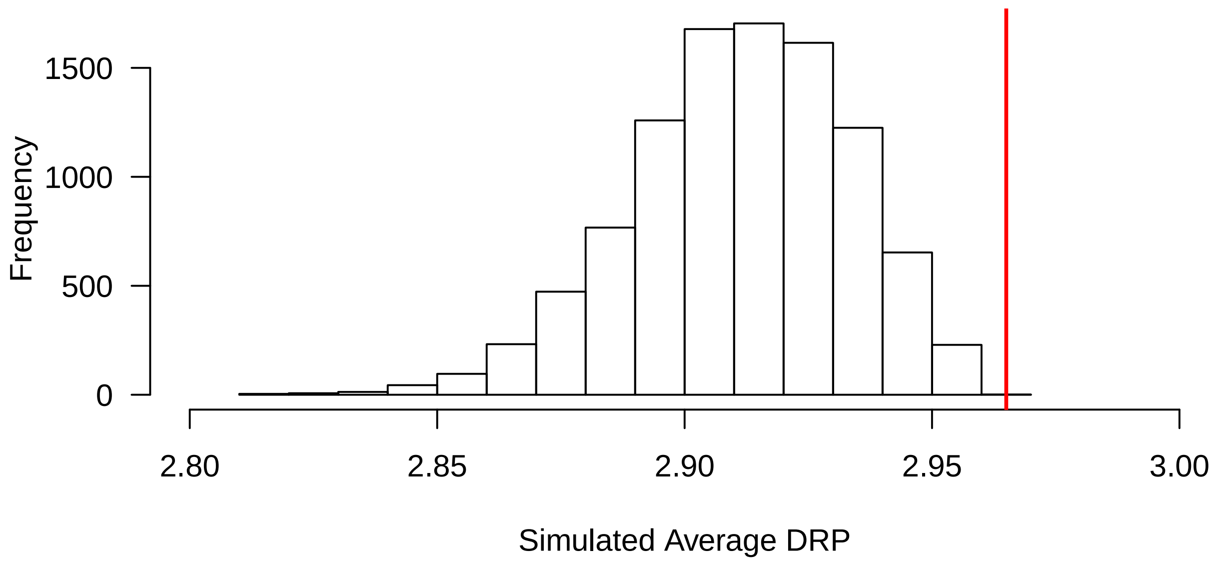

Figure 18: Results of simulation exercise to illustrate the bias of simple averaging. The vertical red line is the estimated DRP at 10 years, as obtained using the Nelson-Siegel curve fitted to Data2. The result is based on the application of R `nls` to the monthly average of the daily yields.

6.2 DRP based on the joint-weighted DRP approach developed by the ERA (WA)

In Table 6A of the addendum report, CEG (2013b) provided estimates of the debt risk premium, calculated using the ERA methodology, for 32 different sub-samples of bonds. The groups of bonds were, of course, categorised on the basis of the following variables: The ratings class of the bonds within the group, the currency in which the bond was issued, whether or not bonds with optionality features were permitted, the data source used (either Bloomberg, UBS rate sheets, or both sources), and the country of domicile of the issuer. CEG (2013b) provided estimates of the DRP in two different columns: In the first column, the jointed-weighted DRP method was applied to bonds with a term to maturity of greater than 2 years; in the second column, the same method was applied to a subset of bonds with terms to maturity in excess of 7 years.

Under the ERA's joint-weighted method, a bond's contribution to the overall result for the DRP is determined by the product of the bond maturity and the issue amount[12]. The calculation used by the ERA (WA) is:

$$\frac{\sum_i (\text{Maturity}_i) \times (\text{Issue Amount}_i) \times (\text{DRP}_i)}{\sum_i (\text{Maturity}_i) \times (\text{Issue Amount}_i)}$$

where:

Maturity_i	=	The remaining term to maturity of a particular bond (to be distinguished from the tenor at issuance).
Issue Amount_i	=	The size of the bond at issuance, measured in $ million. For a plain vanilla, fixed coupon bond, the issue amount can be thought of as the bond's face value.
DRP_i	=	The debt risk premium attributable to the particular bond (bond 'i').

We have used Bootstrap resampling (see, for example, Efron and Tibshirani,1996) to provide standard errors for the DRPs at 10 years based on bonds with tenors greater than 7 years as given in the table. The methodology is as follows:

- The data sub-samples were the source of information on bond yields and issue amounts. Average bond yields over a month were used.
- For each of the rows shown in Table 6A, take a sample of the same size, selected with replacement and calculate the weighted average according to the ERA methodology.
- Repeat the process 1000 times, giving 1000 weighted averages.
- The standard error is the standard deviation of the 1000 weighted averages.

For rows 1 to 4, the results are given in Table 12, together with summaries of 1000 bootstrap simulations based on fitting the `nls` model, without removal of outliers. The bias of the weighted average method is calculated as the difference between the average of the bootstrap simulations based on the weighted averages and the average of the bootstrap simulations based on `nls`, since there was no discernible bias of the `nls` approach.

The bias is caused by a number of factors:

- For maturities at which the yield curve is convex, the estimated DRPs under the ERA (WA) method will tend to be higher.
- For values of the term to maturity at which the curve is concave, the estimated DRPs under the ERA (WA) method will tend to be lower.
- The bias for A- bonds will generally be less pronounced than for BBB+ bonds.
- The bias for BBB+ bonds will generally be less pronounced than for BBB bonds.

[12] The ERA has not stated the credit rating for its benchmark corporate bond.

Row	Table 6A (CEG, 2013b) DRP_{10} (%)	Bootstrap DRP_{10} (%)	Bootstrap SE (%)	Weighted Average (> 7 years) DRP_{10} (%)	SE (%)	Bias (%)	$\sqrt{MSE}$ (%)
1	2.72	2.963	0.109	2.717	0.149	-0.246	0.288
2	2.72	2.966	0.113	2.717	0.155	-0.249	0.293
3	2.73	2.965	0.097	2.735	0.147	-0.23	0.273
4	2.74	2.951	0.105	2.735	0.148	-0.216	0.261

Table 12: ERA methodology results: rows 1 to 4: DRP_{10}.

- The weighting will accentuate the biases above.

The Mean Square Error (MSE) is a combination of the bias and the standard error and is given by

$$MSE = Bias^2 + SE^2.$$

The MSE gives a summary of how close an estimate is to the correct value. The nls estimates are designed to be unbiased, and this is demonstrated by the close equivalence of the original estimates (see Table 7) and the average of the bootstrap simulations based on `nls`. In this case the square root of the MSE is just the standard error. Note that the bias is negative for all rows using the joint-weighted weighted DRP approach and the MSE is always greater using the joint-weighted DRP approach than it is when applying curve fitting.

These results indicate that curve fitting is a better approach than using the joint-weighted DRP approach.

7 Conclusions

Nelson-Siegel curves can be used to estimate term structure models which provide an appropriate and accurate method of determining the cost of debt for different tenors.

CEG (2013a, 2013b) applied Nelson-Siegel equations across a broad database of corporate bonds, and obtained estimates of the debt risk premium which were marginally below 3.0% for a 10 year term to maturity. We have concentrated on the output that was generated by the four main data sub-samples used by CEG, and have been able to produce results that either closely matched those of CEG or else were identical. After undertaking limited re-parameterisation, we were also able to produce standard errors, thereby providing a useful complement to the analysis already undertaken by CEG. Standard errors convey information about the precision of the empirical estimates. The results for the debt risk premium at 10-years, and for the increment to the DRP from 7 to 10 years, were shown to have low standard errors and to therefore be precise.

The non-linear mixed effects model is a robust specification which makes full use of the information that is contained within the daily observations of bond yields. The model takes account of the idiosyncratic aspects of a particular bond and also controls for serial correlation of the daily bond yields. For the largest sub-sample of data, the estimated DRP was 2.99% for a 10 year tenor bond, with a standard error of 0.09%.

The estimation of par yield curves is a worthy exercise because these curves fully standardise and correct for differences between bonds that are caused by variations in the timing and size of coupon payments. We estimated zero-coupon yield curves or spot rate curves that belong to the family of Nelson-Siegel curves. Subsequently, we used these estimates to generate estimates of par yield curves. Schaefer (1977) shows how one can uncover the term structure of par yields from the term structure of spot rates.

Finally, the application of a simulation technique has shown that the curve-fitting method can overcome the deficiencies of both the simple averaging approach (previously applied by the AER), and the joint-weighted averaging approach advocated by the ERA (WA). The two approaches give downwardly biased estimates of the DRP, and the joint-weighted approach is also less precise than using curve-fitting. The loss of precision under the joint-weighted DRP technique is shown by comparatively high values of the mean-squared error (MSE).

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A Starting Values

It is important to have sensible starting values. If the starting values are inappropriate then it is possible for there to be convergence problems and for a particular simulation even to converge to the wrong solution.

One interesting feature of the Nelson-Siegel model is that it is conditionally linear: that is given the value of β_6, the model is linear in the other parameters i.e. the model can be expressed as

$$\text{Yield}(t, \text{rank}) = \beta_1 + \beta_2 X_1 + \beta_3 X_2 + \beta_4 \text{A-} + \beta_5 \text{BBB}$$

where

$$X_1 = \frac{1 - \exp(-t/\exp(\beta_6))}{t/\exp(\beta_6)}$$

and

$$X_2 = \frac{1 - \exp(-t/\exp(\beta_6))}{t/\exp(\beta_6)} - \exp(-t/\exp(\beta_6)).$$

A good strategy is to take β_6 over a range of values, and for each value calculate the other parameters using multiple regression. This has been done in Fig 19 with the residual sum of squares plotted against the value of β_6. This illustrates the problems that can be encountered with inappropiate starting values. Starting values of β_6 above about 1.6 would lead to convergence problems.

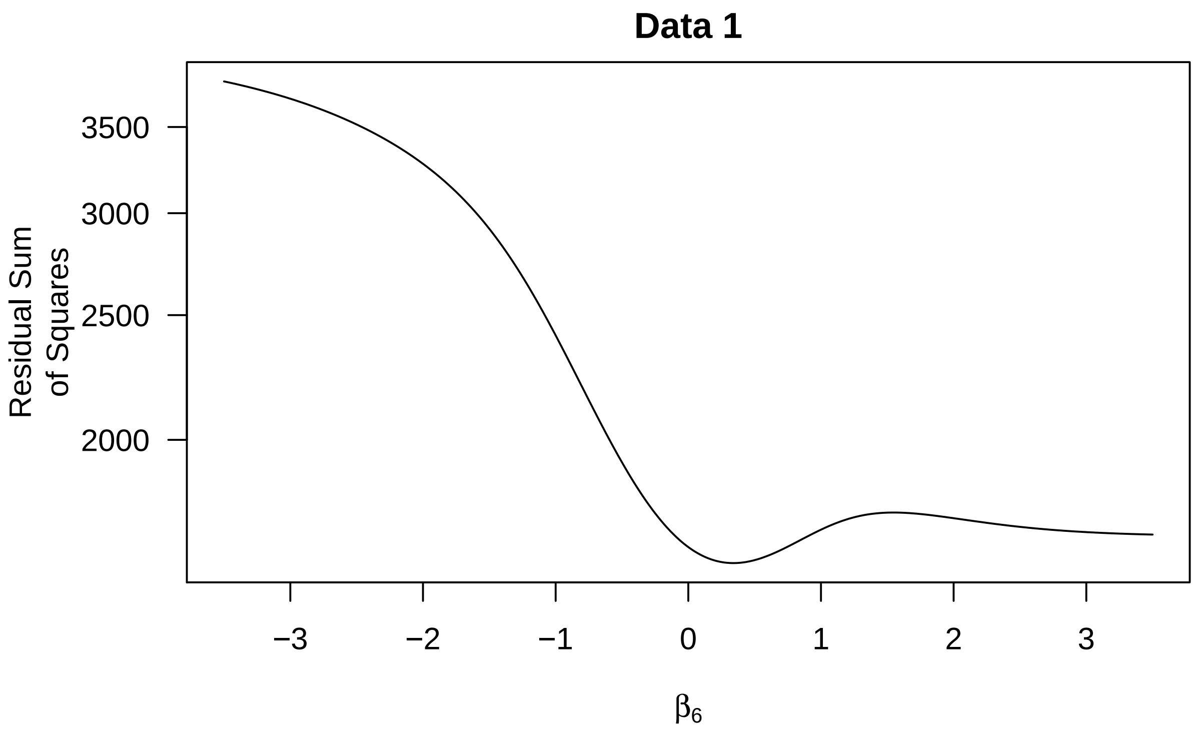

Figure 19: Profile residual sum of squares: Data1.

B Authors

Neil Diamond

Neil Diamond CV

September 2013

Academic Qualifications: B.Sc (Hons) (Monash), Ph.D. (Melbourne), A.Stat

Career History

1977-78	Statistician, ICI Explosives Factory, Deer Park
1979-86	Research Officer, Research Scientist, Senior Research Scientist And Statistics and Computing Team Leader, ICI Central Research Laboratories, Ascot Vale
1987-1989	Lecturer, Department of Mathematics, Computing and Operations Research, Footscray Institute of Technology
(1989)	Visiting Scientist, Center for Quality and Productivity Improvement, University of Wisconsin-Madison, USA.
1990-2003	Senior Lecturer, Department of Computer and Mathematical Sciences, Victoria University of Technology
(1995)	Visiting Fellow, Center for Quality and Productivity Improvement, University of Wisconsin-Madison, USA.
2003-2004	Senior Statistician, Insureware
2004-2006	Senior Lecturer and Deputy Director of Consulting, Department of Econometrics and Business Statistics, Monash University.
2007- 2012	Senior Lecturer and Director of Consulting, Department of Econometrics and Business Statistics, Monash University.
2011- 2012	Associate Professor and Co-ordinator of Statistical Support, Victoria University.
2012-	Director, ESQUANT Statistical Consulting

Research and Consulting Experience

- A Ph.D. from the University of Melbourne entitled "Two-factor interactions in non-regular foldover designs."
- Ten years with ICI Australia as an industrial statistician initially with the Explosives group and eventually with the research group.
- Two six month periods (Professional Experience Program and Outside Studies Program) at the Center for Quality and Productivity Improvement, at the University of Wisconsin-Madison. The Center, founded and directed by Professor George Box, conducts innovative practical research in modern methods of quality improvement and is an internationally recognised forum for the exchange of ideas between experts in various disciplines, from industry and government as well as academia.

- Extensive consulting and training on behalf of the Centre for Applied Computing and Decision Analysis based at VUT for the following companies:

Data Sciences	Initiating Explosives Systems
Analytical Science Consultants	Saftec
Glaxo Australia	Datacraft Australia
Enterprise Australia	ICI Australia
The LEK partnership	Kaolin Australia
BP Australia	AMCOR
Melbourne Water	Kinhill Group
Australian Pulp and Paper Institute	

- Operated the Statistical Consulting Service at Victoria University of Technology from 1992-2003.
- From 2003-2004 worked as a Senior Statistician with Insureware on the analysis of long-tailed liability data.
- From December 2004 to December 2006 Deputy Director of Consulting of Monash University Statistical Consulting Service based in the Department of Econometrics and Business Statistics.
- From January 2007 Director of Consulting of Monash University Statistical Consulting Service based in the Department of Econometrics and Business Statistics.
- Extensive consulting and training on behalf of the Monash University Statistical Consulting Service for the following companies and organisations:

Australian Tax Office	Department of Human Services
J D McDonald	IMI Research
Port of Melbourne Corporation	Incitec Pivot
Agricola, Wunderlich & Associates	Parks Victoria
Australian College of Consultant Physicians	ANZ
Department of Justice	CRF(Colac Otway)
Australian Football League Players' Association	United Energy
ETSA	ENA

Postgraduate Supervision

Principal Supervisor

Gregory Simmons (1994-1997). M.Sc. completed. "Properties of some minimum run resolution IV designs."

Tony Sahama (1995-2003). Ph.D. completed. "Some practical issues in the design and analysis of computer experiments."

Ewa Sztendur (1999-2005). Ph.D. completed. "Precision of the path of steepest ascent in response surface methodology." [As a result of this thesis, Ewa was awarded the 2006 Victoria University Vice-Chancellor's Peak Award for Research and Research Training-Research Degree Graduate.]

Co-supervisor

Keith Hart (1996-1997). M.Sc. completed. "Mean reversion in asset prices and asset allocations in funds management."

Jyoti Behera (1999-2000). M.Eng. completed. "Simulation of container terminals."

Ray Summit (2001-2004). Ph.D. completed. "Analysis of warranty data for automobile data."

Rob Moore (2001-2007). Ph.D. completed. "Computer recognition of musical instruments.

M.Sc. Minor Theses

Milena Shtifelman (1999). Completed. (Monash University Accident Research Centre). "Modelling interactions of factors influencing road trauma trends in Victoria."

Rohan Weliwita (2002). Completed. "Modelling road accident trauma data."

Theses Examination

One M.Sc. major thesis (University of Melbourne) and one M.Sc minor thesis (Victoria University).

Workshops

Victoria University

- Experimental Design.
- Longitudinal Data Analysis.
- Statistics for Biological Sciences.
- Introductory Statistics for Research.

- Software Packages for Statistics.
- Design and Analysis of Questionnaires and Sample Surveys.
- Introductory SPSS.
- Statistics for Biological Sciences using R.
- Statistics for Biological Sciences using SPSS.
- Research Design and Statistics.

Monash University

- Expert Stats Seminars for higher degree research students on Software Packages for Statistics, Questionnaire Design, Analysis of Survey Data, and Multivariate Statistics.
- Introduction to Statistics for Pharmacy (5 hours).

Other

- Design of Experiments for ICI Australia (One day course).
- Design of Experiments for Quality Assurance-including Taguchi Methods. A 2-day professional development short course on behalf of the Centre for Manufacturing Advanced Engineering Centre.
- Design of Experiments for the Australian Pulp and Paper Institute.
- Statistical Methods for ANZ Analytics.

Teaching Experience

Monash University

- Business Statistics (First Year), Marketing Research Analysis (Second Year), Survey Data Analysis (Third Year-Clayton and Caulfield).

Victoria University of Technology

- Applied Statistics (First Year), Linear Statistical Models, Sampling and Data Analysis (Second Year), Experimental Design (Third Year).

- Statistics for Engineers, Statistics for Nurses, Statistics for Occupational Health.
- Forecasting (Graduate Diploma in Business Science)

Sessional Teaching

- RMIT (1991, 1996-2002) Design of Experiments for Masters in Quality Management.
- AGSM (1993-1997): Total Quality Management for Graduate Management Qualification.
- Various other: The University of Melbourne, Enterprise Australia, Swinburne Institute of Technology.

Industry Projects

Over 30 projects for the following companies and organisations:

Gas and Fuel Corporation	Ford Australia
Mobil Australia	Fibremakers
ICI Australia	Western General Hospital
Data Sciences	Keilor City Council
AMCOR	Composite Buyers
Davids	Email Westinghouse
Craft Coverings	Australian Wheat Board
CSL	Holding Rubber
Viplas Olympic	Melbourne Water
Federal Airports Corporation	

Publications

Chapters in Books

1. Sztendur, E.M. and Diamond, N.T., (2001). "Inequalities for the precision of the path of steepest ascent in response surface methodology," in Cho, Y.J, Kim, J.K., and Dragomir, S.S. (eds.) *Inequality Theory and Applications Volume 1*, Nova Publications.

Journal Articles

1. Diamond, N.T., (1991). "Two visits to Wisconsin," *Quality Australia*, **7**, 30-31.

2 Diamond, N.T., (1991). "The use of a class of foldover designs as search designs," *Austral. J. Statist*, **33**, 159-166.

3 Diamond, N.T., (1995). "Some properties of a foldover design," *Austral. J. Statist*, **37**, 345-352.

4 Watson, D.E.R., Hallett, R.F., and Diamond, N.T., (1995). "Promoting a collegial approach in a multidisciplinary environment for a total quality improvement process in higher education, " *Assessment & Evaluation in Higher Education*, **20**, 77–88.

5 Van Matre, J. and Diamond, N.T., (1996). "Team work and design of experiments," Quality Engineering, 9, 343–348.

6 Diamond, N.T., (1999). "Overlap probabilities and delay detonators," *Teaching Statistics*, **21**, 52–53. Also published in "Getting the Best from Teaching Statistics", one of the best 50 articles from volumes 15 to 21 of *Teaching Statistics*.

7 Cerone, P. and Diamond, N.T., (2000). "On summing permutations and some statistical properties," *The International Journal of Mathematical Education in Science and Technology*, **32**, 477-485.

8 Behera, J.M., Diamond, N.T., Bhuta, C.J. and Thorpe, G.R.,(2000). "The impact of job assignment rules for straddle carriers on the throughput of container terminal detectors," *Journal of Advanced Transportation*, **34**, 415-454.

9 Sahama, T. and Diamond, N.T., (2001). "Sample size considerations and augmentation of computer experiments," *The Journal of Statistical Computation and Simulation*, **68**, 307-319.

10 Paul, W. and Diamond, N.T., (2001). "Designing a monitoring program for environmental regulation: Part 1-The operating characteristic curve," *Water*: Journal of Australian Water Association, October 2001, 50-54.

11 Sztendur, E.M. and Diamond, N.T., (2002). "Extension to confidence region calculations for the path of steepest ascent," *Journal of Quality Technology*, **34**, 288-295.

12 Paul, W. and Diamond, N.T., (2002). "Designing a monitoring program for environmental regulation: Part 2-Melbourne Water case study," *Water*: Journal of Australian Water Association, February 2002, 33-36.

13 Steart, D.C., Greenwood, D.R., Boon, P.I. and Diamond, N.T., (2002) "Transport of leaf litter in upland streams of Eucalyptus and Nothofagus forests in South Eastern Australia," *Archiv Für Hydrobiologie,* **156***, 43-61.*

14 Peachey, T. C., Diamond, N. T., Abramson, D. A., Sudholt, W., Michailova, A., and Amirriazi, S. (2008). "Fractional factorial design for parameter sweep experiments using Nimrod/E,"*Sci. Program.*, **16**(2-3), 217–230.

15 Sahama, T.R. and Diamond, N.T. (2009) "Computer Experiment-A case study for modelling and simulation of Manufacturing Systems," *Australian Journal of Mechanical Engineering*, **7**(1), 1–8.

16 Booth, R., Brookes, R., and Diamond, N. (2012) " The declining player share of AFL clubs and league revenue 2001-2009: Where has the money gone?," *Labour and Industry* 22:4, 433–446.

17 Booth, R., Brookes, R., and Diamond, N. (2012) "Theory and Evidence on Player Salaries and Revenues in the AFL 2001-2009," Accepted for publication in *Economics and Labour Relations Review.*

18 Chambers, J.D., Bethwaite, B., Diamond, N.T., Peachey, T.C., Ambramson, D., Petrou, S., and Thomas, E.A. (2012) "Parametric computation predicts a multiplicative interaction between synaptic strength parameters controls properties of gamma oscillations," *Frontiers in Computational Neuroscience* Volume 6, Article 53 doi:103389/fncom.2012.00053.

19 de Bruin, C.L., Deppeler, J.M., Moore, D.W., and Diamond, N.T. (2013) "Public school-based interventions for adolescents and young adults with an autism sprectrum disorder: a meta-analysis," *Review of Educational Research* prepublished 17 September 2013. DOI: 10.3102/0034654313498621

Refereed Conference Papers

1. Behera, J., Diamond, N.T., Bhuta, C. and Thorpe, G., (1999). "Simulation: a decision support tool for improving the efficiency of the operation of road vehicles in container terminals," 9th ASIM Dedicated Conference, Berlin, February 2000, 75-86.

2. Jutrisa, I., Diamond, N.T. and Cerone. P., (1999). "Frame size effects on throughput and return traffic in reliable satellite broadcast transmission, " 16th International Teletraffic Congress, Edinburgh, Scotland.

3. Diamond, N.T. and Sztendur, E.M. (2002). "The use of consulting problems in introductory statistics classes", *Proceedings of the 6th International Conference on the Teaching of Statistics.*

4. Summitt, R.A., Cerone. P., and Diamond, N.T. (2002). "Simulation Reliability Estimation from Early Failure Data, *Proceedings of the Fourth International Conference on Modelling and Simulation*, 368-390.

5. Summitt, R.A., Cerone. P., and Diamond, N.T. (2002). "Simulation Reliability Estimation from Early Failure Data II, *Proceedings of the Fourth International Conference on Modelling and Simulation*, 391-396.

6. Sahama, T. And Diamond, N.T. (2008). "Computer Experiment-A case study for modelling and simulation of Manufacturing Systems," 9th Global Conference on Manufacturing and Management.

7. Jackson, M.L., Diamond, N.T., Sztendur E.M., Bruck, D. (2013). "The Role of Sleep Difficulties in the Subsequent Development of Depression and Anxiety in a Longitudinal Study of Young Australian Women, " *American Professional Sleep Societies Scientific Meeting, Baltimore, MA* (Selected for an Honorable Mention Award) and *25th Annual Scientific Meeting of the Australasian Sleep Association, Brisbane, October*.

Reports

A number of confidential reports for ICI Australia from 1977-1987.

Victoria University

VU1. Diamond, N.T (1990). "Professional Experience Program at the Center for Quality and Productivity Improvement," Footscray Institute of Technology.

VU2. Bisgaard, S. and Diamond, N.T (1991). "A discussion of Taguchi's methods of confirmatory trials," Report No. 60. Center for Quality and Productivity Improvement, University of Wisconsin-Madison.

VU3. Diamond, N.T (1996). "Outside Studies Program at the Center for Quality and Productivity Improvement," Victoria University of Technology.

VU4. Diamond, N.T (1996). "Statistical Analysis of EPA compliance of the western treatment plant," prepared for Melbourne Water on behalf of Kinhill Engineers.

VU5. Diamond, N.T (1996). "Statistical Analysis of EPA compliance of the western treatment plant," prepared for Melbourne Water on behalf of Kinhill Engineers.

VU6. Diamond, N.T (1998). "Statistical Analysis of BOD and SS compliance rates and license limits at ETP and WTP," prepared for Melbourne Water.

VU7. Diamond, N.T (1998). "Fate of pollutants at WTP-method for determining safety margins," prepared for Egis consulting group.

VU8. Bromley, M. and Diamond, N.T (2002). "The manufacture of Laboratory coreboard using various chip furnishes," prepared for Orica adhesives and resins.

Monash University

M1. Hyndman, R.J, Diamond, N.T. and de Silva, A. (2004). "A review of the methodology for identifying potential risky agents," prepared for the Australian Tax Office.

M2. Diamond, N.T. and Hyndman, R.J. (2005). "Sample Size for Maternal and Child Heath Service Evaluation," prepared for the Department of Human Services.

M3. Diamond, N.T. (2005). "Analysis of Customer Satisfaction Survey 2005," prepared for JD Macdonald.

M4. Diamond, N.T. (2005). "Analysis of 2005 Orientation Survey," prepared for Monash Orientation.

M5. Diamond, N.T. (2005). "Analysis of Before and After and Sequential Monadic Concept Consumer Surveys," prepared for IMI-Research.

M6. Diamond, N.T. and Hyndman, R.J. (2005). "The Monash Experience Questionnaire 2003: First Year Students," prepared for CHEQ, Monash University.

M7. Diamond, N.T. and Hyndman, R.J. (2005). "The Monash Experience Questionnaire 2003: The Best and Worst, " prepared for CHEQ, Monash University.

M8. Diamond, N.T. and Hyndman, R.J. (2005). "The Monash Experience Questionnaire 2003: The Best and Worst for First Year Students," prepared for CHEQ, Monash University.

M9. Diamond, N.T. (2005). "Technical Document for DUKC Uncertainty Study," prepared for Port of Melbourne Corporation.

M10. Diamond, N.T. (2005). "DUKC Uncertainty Study-Summary of Results," prepared for Port of Melbourne Corporation.

M11. Diamond, N.T. (2005). "Number of Ship trials for DUKC Uncertainty Study," prepared for Port of Melbourne Corporation.

M12. Diamond, N.T. (2005). "Threshold Criteria for Touch Bottom Probabilities," prepared for Port of Melbourne Corporation.

M13. Diamond, N.T. and Hyndman, R.J. (2006). "The Monash Experience Questionnaire 2005: The Best and Worst," prepared for CHEQ, Monash University.

M14. Diamond, N.T. and Hyndman, R.J. (2006). "The Monash Experience Questionnaire 2005: The Best and Worst for First Year Students," prepared for CHEQ, Monash University.

M15. Diamond, N.T. and Hyndman, R.J. (2006). "The Monash Experience Questionnaire 2005: A Statistical Analysis," prepared for CHEQ, Monash University.

M16. Diamond, N.T. and Hyndman, R.J. (2006). "The Monash Experience Questionnaire 2005: 2005 vs. Pre-2005 Students," prepared for CHEQ, Monash University.

M17. Diamond, N.T. (2006). "Agreement of 110/116 and 111/117 items by Consultant Physicians," prepared for the Australian College of Consultant Physicians.

M18. Diamond, N.T. (2006). "Analysis of Statistical Issues regarding Cornish v Municipal Electoral Tribunal, " prepared for Agricola, Wunderlich & Associates.

M19. Diamond, N.T. (2006). "Analysis of Parks Victoria Staff Allocation," prepared for Parks Victoria.

M20. Diamond, N.T. and Hyndman, R.J. (2006). "Summary of Results of IPL Sales Forecasting Improvement Project," prepared for Incitec Pivot.

M21. Sztendur, E.M. and Diamond, N.T. (2007) "A model for student retention at Monash University", prepared for University retention committee.

M22. Sztendur, E.M. and Diamond, N.T. (2007) "An extension to a model for student retention at Monash University", prepared for University review of coursework committee.

M23. Sztendur, E.M. and Diamond, N.T. (2007) "A model for student academic performance at Monash University", prepared for University review of coursework committee.

M24. Diamond, N.T. (2007). "Analysis of IB student 1st year results at Monash University 2003-2005", prepared for VTAC.

M25. Diamond, N.T. (2008). "Effect of smoking bans on numbers of clients utilising problem gambling counselling and problem gambling financial counselling", prepared for Department of Justice

M26. Diamond, N.T. (2008). "Development of Indices Based Approach for Forecasting Gambling Expenditure at a Local Government Area Level", prepared for Department of Justice

M27. Diamond, N.T. (2008). "Orientation 2007- Analysis of Quantitative results", prepared for University Orientation committee.

M28. Diamond, N.T. (2008). "Orientation 2007- Analysis of Qualitative results, prepared for University Orientation committee.

M29. Diamond, N.T. (2008). "Analysis of Clients presenting to Problem Gambling Counselling Services-2002/03 to 2005/06", prepared for the Department of Justice.

M30. Diamond, N.T. (2008). "Analysis of Clients presenting to Problem Gambling Financial Counselling Services-2001/02 to 2005/06", prepared for the Department of Justice.

M31. Diamond, N.T. (2008). "Analysis of Clients presenting to Problem Gambling Counselling and Problem Gambling Financial Counselling Services-2006/07", prepared for the Department of Justice.

M32. Diamond, N.T. (2008). "The effect of changes to Electronic Gaming Machine numbers on gambling expenditure", prepared for the Department of Justice.

M33. Diamond, N.T. (2009). "Adjustment of Mark Distributions", prepared for the Faculty of Law.

M34. Diamond, N.T. (2009). "Summary of Results for Dyno Nobel Sales Forecasting Improvement Project," prepared for Incitec Pivot.

M35. Diamond, N. and Brooks, R. (2010). "Determining the value of imputation credits: Multicollinearity and Reproducibility Issues", prepared for the Victorian Electricity Distributors.

M36. Booth, R., Diamond, N., and Brooks, R. (2010). "Financial Analysis of Revenues and Expenditures of the AFL and of the AFL Clubs", prepared for the Australian Football League Players' Association.

M37. Diamond, N. and Brooks, R. (2010). "Determining the value of imputation credits: Sample Selection, and Standard Errors", prepared for the Victorian Electricity Distributors.

M38. Diamond, N. and Brooks, R. (2010). "Determining the value of imputation credits: Joint Confidence Region and Other Multicollinearity Issues", prepared for the Victorian Electricity Distributors.

M39. Diamond, N. and Brooks, R. (2010). "Reconstructing the Beggs and Skeels Data Set", prepared for the Victorian Electricity Distributors.

M40. Diamond, N. and Brooks, R. (2010). "Response to AER Final Decision", prepared for the Victorian Electricity Distributors.

M41. Diamond, N. and Sztendur, E. (2011). "The Student Barometer 2010. Faculty Results", prepared for Victoria University (6 reports).

M42. Diamond, N. and Sztendur, E. (2011). "The Student Barometer 2010. Campus Results", prepared for Victoria University.

M43. Diamond, N. and Sztendur, E. (2011). “The Student Barometer 2010. Qualitative analysis of comments”, prepared for Victoria University (17 reports).

M44. Diamond, N. and Brooks, R. (2011). ‘Review of SFG 2011 Dividend Drop-off Study’. prepared for Gilbert and Tobin on behalf of ETSA.

M45. Diamond, N. (2011). ‘A review of “Using capture-mark-recapture methods to estimate fire starts in the United Energy distribution area”, by Rho Environmetrics Pty.Ltd. and John Field Consulting Pty.Ltd’, prepared for United Energy.

M46. Diamond, N., Brooks, R., and Macquarie, L. (2013). ‘Estimation of Fair Value Curves’, prepared for APA Group, Envestra, Multinet Gas, and SP AusNet. 7th February 2013.

ESQUANT Statistical Consulting

E1. Diamond, N.T. and Sztendur, E.M. (2013). “Assistance with Data Mining”, prepared for confidential accounting firm. 21 January 2013.

E2. Diamond, N.T. (2013). “A review of NERA’s analysis of McKenzie and Partington’s EGARCH analysis,’ prepared for Multinet Gas. 9 April 2013 and 5 August 2013.

E3. Gray, S., Hall, J., Diamond, N., and Brooks, R. (2013). “Assessing the reliability of regression-based estimates of risk ,” prepared for Energy Networks Association in conjuction with SFG Consulting and Monash University Statistical Consulting Service. 17 June 2013.

E4. Gray, S., Hall, J., Diamond, N., and Brooks, R. (2013). ‘The Vasicek adjustment to beta estimation in the Capital Asset Pricing Model,” prepared for Energy Networks Association in conjuction with SFG Consulting and Monash University Statistical Consulting Service. 17 June 2013.

E5. Gray, S., Hall, J., Diamond, N., and Brooks, R. (2013). “Comparison of OLS and LAD regression techniques for estimating beta,” prepared for Energy Networks Association in conjuction with SFG Consulting and Monash University Statistical Consulting Service. 26 June 2013.

E6. Diamond, N.T. and Young, D. (2013). “Estimating Benchmark Distributions,” For Chorus, in conjuction with Competition Economists Group. 2nd September 2013.

E7. Diamond, N.T. (2013). “Design of Sampling and Testing Program for Particleboard & MDF,” for Engineered Wood Products Association of Australia. 6 September 2013.

E8. Diamond, N.T. (2013). "Regression Analysis for Credit Rating," For Competition Economists Group. 17 September 2013.

E9. Diamond, N.T. (2013). "Cross-checking of ERA (WA) beta estimates," For Competition Economists Group. 18 September 2013.

E10. Diamond, N.T. and Brooks, R. (2013). "Review of ERA (WA) yield curve analysis," For United Energy and Multinet Gas. 26 September 2013.

R Packages (Extensions to R Programming Environment)

R1. Diamond, N.T. (2010), VizCompX, http://cran.r-project.org/web/packages/VizCompX

Professional Service

- President, Victorian Branch, Statistical Society of Australia, 2001-2002.
  - Terms as Council Member, Vice-President, and Past President.
- Referee: *Australian and New Zealand Journal of Statistics*, *Biometrika*, *Journal of Statistical Software*

Professor Robert Brooks

Robert Brooks is a professor in the Department of Econometrics and Business Statistics and Deputy Dean, Education in the Faculty of Business and Economics.

Robert obtained his honours and PhD degrees from Monash University and has previously worked at RMIT University.

His primary area of research interest is in financial econometrics, with a particular focus on beta risk estimation, volatility modelling and the analysis of the impacts of sovereign credit rating changes on financial markets. His research in the financial econometrics area has produced a number of publications in top-tier journals, along with research funding from ARC Discovery and ARC Linkage and industry sources.

Given his education management role, Robert also works in areas of educational research relating to pedagogy of teaching business statistics and in particular applications of problem based learning in that setting.

Publications

Books

Brooks, R.D., Morley, C.L., Kam, B., Stewart, M., Diggle, J., Gangemi, M., 2003, *Benefits of Road Investment to Assist Tourism*, Austroads Incorporated, Sydney NSW Australia.

Brooks, R.D., Fausten, D.K., 1998, *Macroeconomics in the Open Economy*, Longman, Melbourne Vic Australia.

Book Chapters

Iqbal, J., Brooks, R., Galagedera, D., 2011, Testing the lower partial moment asset-pricing models in emerging markets, in *Financial Econometrics Modeling: Market Microstructure, Factor Models and Financial Risk Measures*, eds Greg N Gregoriou and Razvan Pascalau, Palgrave Macmillan, Basingstoke UK, pp. 154-175.

Booth, D., Brooks, R., 2011, Violence in the Australian Football League: Good or bad?, in *Violence and Aggression in Sporting Contests: Economics, History and Policy*, eds R Todd Jewell, Springer Science+Business Media, New York NY USA, pp. 133-151.

Lim, K., Brooks, R.D., 2010, Are emerging stock markets less efficient? A survey of empirical literature, in *Emerging Markets: Performance, Analysis and Innovation*, eds Greg N Gregoriou, CRC Press, Boca Raton FL USA, pp. 21-38.

Iqbal, J., Brooks, R.D., Galagedera, D.U.A., 2010, Asset pricing with higher-order co-moments and alternative factor models: The case of an emerging market, in *Emerging Markets: Performance, Analysis and Innovation*, eds Greg N Gregoriou, CRC Press, Boca Raton FL USA, pp. 509-531.

Woodward, G., Brooks, R.D., 2010, The market timing ability of Australian superannuation funds: Nonlinearities and smooth transition models, in *The Risk Modeling Evaluation Handbook: Rethinking Financial Risk Management Methodologies in the Global Capital Markets*, eds Greg N Gregoriou, Christian Hoppe and Carsten S Wehn, McGraw-Hill, USA, pp. 59-73.

Bissoondoyal-Bheenick, E., Brooks, R.D., 2010, Volatility asymmetry and leverage: Some U.S. evidence, in *The Risk Modeling Evaluation Handbook: Rethinking Financial Risk Management*

Methodologies in the Global Capital Markets, eds Greg N Gregoriou, Christian Hoppe and Carsten S Wehn, McGraw-Hill, USA, pp. 115-123.

Dimovski, W., Brooks, R.D., 2007, Differences in underpricing returns between REIT IPOs and industrial company IPOs, in *Advances in Quantitative Analysis of Finance and Accounting - Volume 5*, eds Cheng-Few Lee, World Scientific, Singapore, pp. 215-225.

Brooks, R.D., Faff, R., Fry, T.R.L., Gunn, L.D., 2005, Censoring and its impact on beta risk estimation, in *Advances in Investment Analysis and Portfolio Management (New Issue) Volume 1*, eds Cheng F. Lee and Alice C. Lee, Center for Pacific Basin Business, Economics, and Finance Research, New Jersey, pp. 111-136.

Brooks, R.D., Merlot, E.S., 2005, Changing candidature approval processes: a review of the RMIT business panel review of candidature process, in *Supervising postgraduate research: contexts and processes, theories and practices*, eds Pam Green, RMIT University Press, Melbourne Vic Australia, pp. 178-201.

Boucher, C., Brooks, R.D., 2005, Changing times, changing research, changing degrees: supervising and managing the first PhD by project undertaken in a business faculty, in *Supervising postgraduate research: contexts and processes, theories and practices*, eds Pam Green, RMIT University Press, Melbourne Vic Australia, pp. 73-88.

Brooks, R.D., Faff, R.W., Fry, T.R.L., Maldonado-Rey, D., 2004, Alternative beta risk estimators in emerging markets: the Latin American case, in *Latin American Financial Markets: Developments in Financial Innovations*, eds H Arbelaez, R Click, Elsevier Ltd, Oxford UK, pp. 329-344.

Brooks, R.D., Sayers, R., 2002, Trends in printed matter exports, in *The International Publishing Services Market: Emerging Markets for Books, from Creator to Consumer*, eds Bill Cope and Christopher Ziguras, Common Ground, Altona Vic Australia, pp. 27-38.

Faff, R., Brooks, R.D., Tan, P.F., 2001, A test of a new dynamic CAPM, in *Advances in Investment Analysis and Portfolio Management Volume 8*, eds Cheng Few Lee, Elsevier Science, Oxford, pp. 133-159.

Journal Articles

Treepongkaruna, S., Brooks, R.D., Gray, S., 2012, Do trading hours affect volatility links in the foreign exchange market?, *Australian Journal of Management [P]*, vol 37, issue 1, Sage Publications Ltd, London UK, pp. 7-27.

Chan, K., Treepongkaruna, S., Brooks, R., Gray, S., 2011, Asset market linkages: Evidence from financial, commodity and real estate assets, *Journal of Banking and Finance [P]*, vol 35, issue 6, Elsevier BV, Amsterdam Netherlands, pp. 1415-1426.

Brooks, R., 2011, CO2 emissions and economic growth: Structural breaks and market reforms in the case of China, *The International Journal of Climate Change: Impacts and Responses [E]*, vol 2, issue 3, Common Ground Publishing, Altona Vic Australia, pp. 25-36.

Luo, W., Brooks, R., Silvapulle, P., 2011, Effects of the open policy on the dependence between the Chinese 'A' stock market and other equity markets: An industry sector perspective, *Journal of International Financial Markets, Institutions and Money [P]*, vol 21, issue 1, Elsevier BV, Amsterdam Netherlands, pp. 49-74.

Bissoondoyal-Bheenick, E., Brooks, R., Hum, X., Treepongkaruna, S., 2011, Sovereign rating changes and realized volatility in Asian foreign exchange markets during the Asian crisis, *Applied Financial Economics [P]*, vol 21, issue 13, Routledge, Abingdon UK, pp. 997-1003.

Masters, T., Russell, R., Brooks, R., 2011, The demand for creative arts in regional Victoria, Australia, *Applied Economics [P]*, vol 43, issue 5, Routledge, Abingdon UK, pp. 619-629.

Lim, K., Brooks, R., 2011, The evolution of stock market efficiency over time: A survey of the empirical literature, *Journal Of Economic Surveys [P]*, vol 25, issue 1, Wiley-Blackwell Publishing Ltd, Oxford UK, pp. 69-108.

Guo, H., Brooks, R., Fung, H., 2011, Underpricing of Chinese initial public offerings, *The Chinese Economy [P]*, vol 44, issue 5, M E Sharpe Inc, Armonk NY USA, pp. 72-85.

Dimovski, W., Philavanh, S., Brooks, R., 2011, Underwriter reputation and underpricing: Evidence from the Australian IPO market, *Review of Quantitative Finance and Accounting [P]*, vol 37, issue 4, Springer, Secaucus NJ USA, pp. 409-426.

Brooks, R., Di Iorio, A., Faff, R., Fry, T., Joymungul, Y., 2010, Asymmetry and time variation in exchange rate exposure: An investigation of Australian stocks returns, *International Journal of Commerce and Management [P]*, vol 20, issue 4, Emerald Group Publishing Ltd, UK, pp. 276-295.

Guo, H., Brooks, R.D., Shami, R.G., 2010, Detecting hot and cold cycles using a Markov regime switching model-Evidence from the Chinese A-share IPO market, *International Review of Economics and Finance [P]*, vol 19, issue 2, Elsevier BV, North-Holland, Netherlands, pp. 196-210.

Bissoondoyal-Bheenick, E., Brooks, R.D., 2010, Does volume help in predicting stock returns? An analysis of the Australian market, *Research in International Business and Finance [P]*, vol 24, issue 2, JAI Press Inc, USA, pp. 146-157.

Iqbal, J., Brooks, R.D., Galagedera, D.U.A., 2010, Multivariate tests of asset pricing: Simulation evidence from an emerging market, *Applied Financial Economics [P]*, vol 20, issue 5, Routledge, UK, pp. 381-395.

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Suntah, N., Brooks, R., 2010, The stock exchange of Mauritius: A study of segmentation versus integration at the regional and global level, *African Journal of Accounting, Economics, Finance and Banking Research [P]*, vol 6, issue 6, Global Business Investments and Publications LLC, USA, pp. 32-41.

Nguyen, H., Dimovski, W., Brooks, R., 2010, Underpricing, risk management, hot issue and crowding out effects: Evidence from the Australian resources sector initial public offerings, *Review of Pacific Basin Financial Markets and Policies [P]*, vol 13, issue 3, World Scientific Publishing Co Pte Ltd, Singapore, pp. 333-361.

Hill, P., Brooks, R.D., Faff, R., 2010, Variations in sovereign credit quality assessments across rating agencies, *Journal of Banking and Finance [P]*, vol 34, issue 6, Elsevier BV, North-Holland, Netherlands, pp. 1327-1343.

Zhang, X., Brooks, R.D., King, M.L., 2009, A Bayesian approach to bandwidth selection for multivariate kernel regression with an application to state-price density estimation, *Journal of Econometrics [P]*, vol 153, issue 1, Elsevier BV, North-Holland, Netherlands, pp. 21-32.

Brooks, R.D., Fry, T.R.L., Dimovski, W., Mihajilo, S., 2009, A duration analysis of the time from prospectus to listing for Australian initial public offerings, *Applied Financial Economics [P]*, vol 19, issue 3, Routledge, United Kingdom, pp. 183-190.

Lim, K., Brooks, R.D., 2009, Are Chinese stock markets efficient? Further evidence from a battery of nonlinearity tests, *Applied Financial Economics [P]*, vol 19, issue 2, Routledge, United Kingdom, pp. 147-155.

Brooks, R.D., Faff, R., Mulino, D., Scheelings, R., 2009, Deal or no deal, that is the question: The impact of increasing stakes and framing effects on decision-making under risk, *International Review of Finance [P]*, vol 9, issue 1-2, Wiley-Blackwell Publishing Asia, Richmond Vic Australia, pp. 27-50.

Woodward, G., Brooks, R.D., 2009, Do realized betas exhibit up/down market tendencies?, *International Review of Economics and Finance [P]*, vol 18, issue 3, Elsevier BV, North-Holland, The Netherlands, pp. 511-519.

Mulino, D., Scheelings, R., Brooks, R.D., Faff, R., 2009, Does risk aversion vary with decision-frame? An empirical test using recent game show data, *Review of Behavioral Finance [P]*, vol 1, issue 1-2, John Wiley & Sons Ltd, UK, pp. 44-61.

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Nandha, M.S., Brooks, R.D., 2009, Oil prices and transport sector returns: An international analysis, *Review of Quantitative Finance and Accounting [P]*, vol 33, issue 4, Springer New York LLC, United States, pp. 393-409.

Lim, K., Brooks, R.D., 2009, On the validity of conventional statistical tests given evidence of nonsynchronous trading and nonlinear dynamics in returns generating process: A further note, *Applied Economics Letters [P]*, vol 16, issue 6, Routledge, United Kingdom, pp. 649-652.

Lim, K., Brooks, R.D., 2009, Price limits and stock market efficiency: Evidence from rolling bicorrelation test statistic, *Chaos, Solitons and Fractals [P]*, vol 40, issue 3, Pergamon, United Kingdom, pp. 1271-1276.

Brooks, R.D., Di lorio, A., Faff, R., Wang, Y., 2009, Testing the integration of the US and Chinese stock markets in a Fama-French framework, *Journal of economic integration [P]*, vol 24, issue 3, Sejong University, Center for International Economics, Republic of Korea, pp. 435-454.

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Curriculum Vitae

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Key Practice Areas

Daniel is a Senior Economist working in CEG's Sydney office with extensive experience in the economic analysis of firms and markets. He has advised regulators, law firms and businesses on a range of issues across industry sectors including electricity, gas, telecommunications, transport, mining and finance.

Daniel has particular expertise in the application of mathematical and computational modelling techniques in economic analysis. His experience spans the design and construction of telecommunications cost models, building regulatory cost models, merger modelling, estimation of the cost of capital, calculating economic damages and econometric modelling. These techniques have formed the basis of expert reports provided to courts and regulators in Australia, New Zealand, the United Kingdom, the Netherlands, Hong Kong, Macau and Samoa.

Daniel was previously an analyst at NERA Economic Consulting. Daniel has a Masters of Commerce (in Economics) with first class honours and Bachelor degrees in Commerce and Science, majoring in Economics and Operations Research respectively.

Selected Projects

- Advised Chorus New Zealand on the Commerce Commission's proposed method of determining the UCLL price in New Zealand by benchmarking against prices in other jurisdictions
- Advice to the Australian Energy Market Commission on barriers to entry in electricity generation
- Assisting the ACCC in developing its analysis about the competitive effects of two recent proposed acquisitions in the media sector
- Advised Everything Everywhere UK on its submissions and appeal in respect of Ofcom's decision on mobile termination rates
- Advising Optus on appropriate principles for fixed line pricing and the formation of a roll-forward regulatory regime. Responding to and identifying a critical error in the proposed pricing principles
- Developing mobile cost models for Digicel in Samoa, Papua New Guinea and Tahiti for submission in regulatory proceedings.
- Estimating benchmarks for mobile termination prices using econometric analysis for Digicel in Vanuatu and Tonga
- Making adjustments to the ACCC's fixed line cost model to estimate the cost of a fibre to the premise roll out in Australia for Optus

- Estimating the potential cost improvements that could be achieved within the ACCC's fixed line cost model by the use of Steiner trees rather than minimum spanning trees on behalf of the Competition Carriers' Coalition
- Constructing spreadsheet models of the price effects of a major proposed merger in the European pharmaceutical industry
- Estimating a reserve price in Commercial Radio Australia's auction of unallocated multiplexer capacity
- Assisted in the preparation of expert statements on the likely impact of the joint venture of the Pilbara iron ore assets of BHP Billiton and Rio Tinto and before that the proposed merger between these parties
- Assisted in the preparation of an expert report on the competitive implications of a merger in the industrial packaging sector
- Analysis of the appropriate cost of capital to be used proposed damages claim being brought by Deutsche Telecom against Vivendi in relation to alleged unlawful activity in a Polish mobile telephony joint venture
- Assisted a European firm examining the implications for competition in the United Kingdom electricity generation market of a number of proposed transactions
- Developed a mobile cost model for an Australian telecommunications company.
- Estimating the likely response in the demand for electricity to the increased proliferation of time of day and critical peak tariffs as part of the MCE's cost/benefit analysis of the introduction of smart meters
- Assisted in the preparation of expert reports for Telecom New Zealand on the correct methodology for calculating the cost of providing the TSO (universal service obligation) using new entrant costs
- Prepared estimates of the potential damages faced by Telstra under a class action lawsuit from shareholders
- Provided drafting and analytical assistance for an expert report examining the effect of Foxtel's proposed special access undertaking on competition in the market for subscription television services
- Contributed to an analysis of the extent of competition in the auto-fuel retail sector in Hong Kong by estimating the margins of local firms and developing international comparisons as benchmarks
- Development of a modelling framework for the ACCC analysing the effect on competition of a merger between electricity generator and advised on potential divestitures

FEDERAL COURT OF AUSTRALIA

Practice Note CM 7

EXPERT WITNESSES IN PROCEEDINGS IN THE FEDERAL COURT OF AUSTRALIA

Practice Note CM 7 issued on 1 August 2011 is revoked with effect from midnight on 3 June 2013 and the following Practice Note is substituted.

Commencement

1. This Practice Note commences on 4 June 2013.

Introduction

2. Rule 23.12 of the Federal Court Rules 2011 requires a party to give a copy of the following guidelines to any witness they propose to retain for the purpose of preparing a report or giving evidence in a proceeding as to an opinion held by the witness that is wholly or substantially based on the specialised knowledge of the witness (see **Part 3.3 - Opinion** of the *Evidence Act 1995* (Cth)).

3. The guidelines are not intended to address all aspects of an expert witness's duties, but are intended to facilitate the admission of opinion evidence[1], and to assist experts to understand in general terms what the Court expects of them. Additionally, it is hoped that the guidelines will assist individual expert witnesses to avoid the criticism that is sometimes made (whether rightly or wrongly) that expert witnesses lack objectivity, or have coloured their evidence in favour of the party calling them.

<u>**Guidelines**</u>

1. General Duty to the Court[2]

1.1 An expert witness has an overriding duty to assist the Court on matters relevant to the expert's area of expertise.

1.2 An expert witness is not an advocate for a party even when giving testimony that is necessarily evaluative rather than inferential.

1.3 An expert witness's paramount duty is to the Court and not to the person retaining the expert.

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[1] As to the distinction between expert opinion evidence and expert assistance see *Evans Deakin Pty Ltd v Sebel Furniture Ltd* [2003] FCA 171 per Allsop J at [676].

[2] The "*Ikarian Reefer*" (1993) 20 FSR 563 at 565-566.

2. The Form of the Expert's Report[3]

2.1 An expert's written report must comply with Rule 23.13 and therefore must

(a) be signed by the expert who prepared the report; and

(b) contain an acknowledgement at the beginning of the report that the expert has read, understood and complied with the Practice Note; and

(c) contain particulars of the training, study or experience by which the expert has acquired specialised knowledge; and

(d) identify the questions that the expert was asked to address; and

(e) set out separately each of the factual findings or assumptions on which the expert's opinion is based; and

(f) set out separately from the factual findings or assumptions each of the expert's opinions; and

(g) set out the reasons for each of the expert's opinions; and

(ga) contain an acknowledgment that the expert's opinions are based wholly or substantially on the specialised knowledge mentioned in paragraph (c) above[4]; and

(h) comply with the Practice Note.

2.2 At the end of the report the expert should declare that "[the expert] has *made all the inquiries that* [the expert] *believes are desirable and appropriate and that no matters of significance that* [the expert] *regards as relevant have, to* [the expert's] *knowledge, been withheld from the Court*."

2.3 There should be included in or attached to the report the documents and other materials that the expert has been instructed to consider.

2.4 If, after exchange of reports or at any other stage, an expert witness changes the expert's opinion, having read another expert's report or for any other reason, the change should be communicated as soon as practicable (through the party's lawyers) to each party to whom the expert witness's report has been provided and, when appropriate, to the Court[5].

2.5 If an expert's opinion is not fully researched because the expert considers that insufficient data are available, or for any other reason, this must be stated with an indication that the opinion is no more than a provisional one. Where an expert witness who has prepared a report believes that it may be incomplete or inaccurate without some qualification, that qualification must be stated in the report.

2.6 The expert should make it clear if a particular question or issue falls outside the relevant field of expertise.

2.7 Where an expert's report refers to photographs, plans, calculations, analyses, measurements, survey reports or other extrinsic matter, these must be provided to the opposite party at the same time as the exchange of reports[6].

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[3] Rule 23.13.
[4] See also *Dasreef Pty Limited v Nawaf Hawchar* [2011] HCA 21.
[5] The *"Ikarian Reefer"* [1993] 20 FSR 563 at 565
[6] The *"Ikarian Reefer"* [1993] 20 FSR 563 at 565-566. See also Ormrod *"Scientific Evidence in Court"* [1968] Crim LR 240

3. Experts' Conference

3.1 If experts retained by the parties meet at the direction of the Court, it would be improper for an expert to be given, or to accept, instructions not to reach agreement. If, at a meeting directed by the Court, the experts cannot reach agreement about matters of expert opinion, they should specify their reasons for being unable to do so.

J L B ALLSOP
Chief Justice
4 June 2013

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TERMS OF REFERENCE – REVIEW OF FAIR VALUE CURVES AND AN ASSESSMENT OF METHODS USED TO DETERMINE THE SPOT COST OF DEBT

Background

On 30th August 2013, the Australian Energy Regulator (AER) published its draft rate of return guideline that will form the basis of the regulated rate of return to be applied in energy network decisions made from 2014 onwards. Previously the AER published an Issues Paper on 18th December 2012 and a Consultation Paper on 10th May 2013.

Under the new Rules, promulgated by the Australian Energy Market Commission, (AEMC), in December 2012, fundamental changes have been made to the way in which the allowance for the return of debt can be determined. Clause 6.5.2(j) of the National Electricity Rules (NER) provides that, at each determination, the allowance for the return of debt can be computed in one of three different ways:

(1) The return that would be required by debt investors in a benchmark efficient entity if it raised debt at the time or shortly before the making of the distribution determination for the regulatory control period.

(2) The average return that would have been required by debt investors in a benchmark efficient entity if it raised debt over an historical period prior to the commencement of a regulatory year in the regulatory control period; or

(3) Some combination of the returns referred to in subparagraphs (1) and (2). Implicit in these considerations is that the regulatory framework should encourage efficient financing practices that the former approach did not explicitly consider.

Implicit in these considerations is that the regulatory framework should encourage efficient financing practices that the previous approach did not explicitly consider.

The calculation of the spot cost of debt, or the market cost of debt at a particular point in time remains an essential component of all three of the aforementioned approaches. Option one, which is known as the rate-on-the day approach, uses an estimate of the cost of debt that is determined over a limited number of days in advance of the commencement of a new regulatory period. Option two calculates a form of historical average cost of debt, using historic information on spot rates. Under option three, the base cost of debt may be estimated separately from the debt risk premium.

United Energy and Multinet Gas are seeking a suitably qualified consultant to undertake specific analysis in relation to the current cost of debt, as measured over a recent 20 to 30 day averaging period. The purpose of the current exercise is to investigate whether yield curves can be used to derive robust estimates of the cost of debt for a benchmark corporate bond with a ten-year tenor.

The consultant will be supplied with:

- A spread sheet database containing information about the characteristics of bonds used in the empirical analysis. The attributes covered will include credit ratings, maturity dates, and yields. Data covering plain vanilla bonds will, in the main, be provided, although there may also be results for callable bonds and other types of bonds. Both domestic and foreign currency bonds will be supplied, although the yields on the latter will have been swapped into Australian dollar yields.

- A report from CEG which contains empirical estimates of yield curves. Please refer to: *Estimating the debt risk premium* (Incorporating CEG notice of errata, 22nd August 2013), prepared for the Energy Networks Association by the Competition Economists Group, August 2013. The report discusses yield curves that have been estimated according to the methods of Nelson and Siegel (1987)[1]. The report also contains an assessment of the performance of the Bloomberg fair value curve for BBB+ corporate debt.

- Regression results will have been reported in a spread sheet workbook. Program code may be supplied if it is available.

Scope of work

The consultant is required to undertake a detailed review of the yield curves that have been estimated by CEG, with a view to assessing the merits of the overall approach. The yield curves are a tool for working out the benchmark cost of debt corresponding to a particular term to maturity. The Nelson-Siegel model is non-linear in the parameters and is therefore more complicated to fit than a normal regression model.

The consultant should assess the case for using yield curves by comparison with the method of direct averaging of observed bond yields. The direct averaging technique takes a simple arithmetic average of bond yields, and has been applied by the AER and the Economic Regulation Authority (Western Australia).

The consultant should also develop yield curves for zero coupon bonds, and par yield curves. A zero coupon bond is a fixed income investment that provides only one payment at maturity. Bonds which trade at par are those for which the calculated yield is equal to the coupon rate. Par yield curves provide a theoretically correct specification for the term structure of the cost of debt.

Preliminary review of CEG methods

(1) Investigate the equations which have been estimated by CEG and seek to reproduce the reported results using a suitable software package. Categorise the results from yield-to-maturity curves separately from the results for par value yield curves. Assess how the estimated equations vary according to the bond samples used.

[1] Nelson, C.R. and Siegel, A.F. (1987). "Parsimonious Modeling of Yield Curves," The Journal of Business, 60, pages 473-489.

(2) Examine and report on the accuracy and correctness of the results from the estimated equations. Check whether outliers are present, and review the regression diagnostics. Note the standard errors and report on the precision of the parameter estimates.

(3) Assess whether the estimates of the cost of debt that have been presented by CEG are justifiable in the context of the estimated yield curves.

Refinements to the analysis – for both types of yield curve

(4) Investigate the case for the use of alternative estimation methods, such as robust regression techniques, for the daily regressions. Compare the results from different estimation methods.

(5) Examine the day-to-day drift of the parameter estimates over the nominated days of the averaging period. Suggest an alternative method for combining the daily results for the estimated benchmark 10-year corporate bond yield.

(6) Examine the validity of restrictions that may be imposed upon the Nelson-Siegel curves. The types of restriction are likely to include different intercept terms for bonds in different credit rating bands.

(7) The empirical methods that are applied to derive par value yield curves are more advanced. Firstly, a zero coupon yield curve is estimated. Secondly, a further non-linear equation has to be solved in order to determine par value yields. Diagnostic tests are needed for the overall model, and these should be developed by the consultant. The consultant should also investigate the impact of the weighting scheme based on Macaulay duration[2].

(8) Evaluate the results for the cost of debt that have been determined as par value yields. Comment on the methods that have been applied.

Comparison of results from yield curves with those obtained using the methods applied separately by the AER and the Economic Regulation Authority (WA).

(9) Critically assess the statistical properties of the cost of debt estimators developed separately by the AER and the ERA (WA). Consider the use of an overall measure of usefulness such as mean squared error (which is equal to the sum of the variance and the bias squared).

(10) Undertake a simulation analysis and apply other methods as appropriate.

Timeframe

The consultant is to provide a draft report which discusses the results of the analysis by Monday 23rd September 2013. A final report should be provided by no later than Monday 7th October.

[2] CEG (2012), Estimating the regulatory debt risk premium for Victorian gas businesses, a report prepared by Dr Tom Hird for APA Group, Envestra, Multinet Gas, and SP AusNet, Competition Economists Group, March 2012; page 31. A standard measure of risk is the Macaulay duration which computes the average maturity of a bond using the present values of its cash flows as weights.

Reporting

Jeremy Rothfield will serve as the primary contact for the period of the engagement. The consultant will prepare reports showing the work-in-progress on a regular basis. The consultant will make periodic presentations on analysis and advice as appropriate.

The consultant is likely to be called upon to present analysis and advice to the cost of capital sub-group of the Energy Networks Association (ENA).

Conflicts

The consultant is to identify any current or potential future conflicts.

Compliance with the Code of Conduct for Expert Witnesses

Attached is a copy of the Federal Court's Practice Note CM 7, entitled "Expert Witnesses in Proceedings in the Federal Court of Australia", which comprises the guidelines for expert witnesses in the Federal Court of Australia (Expert Witness Guidelines).

Please read and familiarise yourself with the Expert Witness Guidelines, and comply with them at all times in the course of your engagement with United Energy and Multinet Gas.

In particular, your report prepared for United Energy and Multinet Gas should contain a statement at the beginning of the report to the effect that the author of the report has read, understood and complied with the Expert Witness Guidelines.

Your report must also:

1. Contain particulars of the training, study or experience by which the expert has acquired specialised knowledge.

2. Identify the questions that the expert has been asked to address.

3. Set out separately each of the factual findings or assumptions on which the expert's opinion is based.

4. Set out each of the expert's opinions separately from the factual findings or assumptions.

5. Set out the reasons for each of the expert's opinions; and

6. Otherwise comply with the Expert Witness Guidelines.

The expert is also required to state that each of the expert's opinions is wholly or substantially based on the expert's specialised knowledge.

The declaration contained within the report should be that "[the expert] has made all the inquiries that [the expert] believes are desirable and appropriate and that no matters of significance that [the expert] regards as relevant have, to [the expert's] knowledge, been withheld from the report".

Please also attach a copy of these terms of reference to the report.

Fees

The consultant is requested to submit:

- A fixed total fee for the project and hourly rates for the proposed project team should additional work be required; and
- Details of the individuals who will provide the strategic analysis and advice.

Contacts

Any questions regarding this terms of reference should be directed to:

Jeremy Rothfield, telephone (03) 8846 9854, or via email at Jeremy.Rothfield@ue.com.au