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11th October 2013

Our Reference: UE.SU.01

Mr Chris Pattas
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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)

Please find enclosed a submission to the AER's draft rate of return guideline which has been prepared on behalf of United Energy and Multinet Gas. The submission has been authored by an independent expert, ESQUANT Statistical Consulting, and is entitled *"A review of NERA's analysis of McKenzie and Partington's EGARCH analysis"*, 5th August 2013. The report by ESQUANT confirms a finding by NERA Economic Consulting that McKenzie and Partington made significant errors in the course of their endeavour to derive an EGARCH model.

Yours sincerely,

Jeremy Rothfield
Network Regulation and Compliance Manager

ESQUANT
Statistical Consulting

A review of NERA's analysis of McKenzie and Partington's EGARCH analysis

A report for United Energy and Multinet Gas

Neil Diamond, B.Sc.(Hons), Ph.D., A.Stat.

August 5, 2013

Contents

1 Terms of reference

United Energy and Multinet Gas are seeking your expert assistance in relation to the approach taken by the AER to the estimation of the cost of equity, and to the determination of the weighted average cost of capital, (WACC), more generally.

Specifically, your input is required in connection with a report prepared by NERA Economic Consulting, *The Market, Size and Value Premiums, A report for the Energy Networks Association*, June 2013. NERA has undertaken an analysis of the risk-free rate and the MRP, and has reviewed the following reports prepared for the AER:

- Review of regime switching framework and critique of survey evidence, Michael McKenzie and Graham Partington on behalf of the Securities Industry Research Centre of Asia-Pacific (SIRCA) Limited, report dated September 7th 2012.
- Review of NERA report on the Black CAPM, Michael McKenzie and Graham Partington on behalf of the Securities Industry Research Centre of Asia-Pacific (SIRCA) Limited, report dated August 24th 2012.
- Report to Corrs Chambers Westgarth, Equity Market Risk Premium, Michael McKenzie and Graham Partington on behalf of XTR Pty. Ltd., report dated December 21st 2011.
- Report to the AER, supplementary report on the equity market risk premium, Michael McKenzie and Graham Partington on behalf of the Securities Industry Research Centre of Asia-Pacific (SIRCA) Limited, report dated February 22nd, 2012.

You are asked to review the report prepared by NERA and to consider the questions presented below which are germane to appendix A and appendix B.2 of the NERA document:

1. Is the EGARCH model prepared by McKenzie and Partington correctly specified?
2. Can you calculate the unconditional volatility of the excess return to the market portfolio that results from, or is implied by, the EGARCH parameter estimates that McKenzie and Partington provide and compare the value that you produce with the estimates that Brailsford, Handley and Maheswaran (2012) supply?
3. Can you ascertain whether Figure 7 in the McKenzie and Partington review of the regime-switching framework report could reasonably have been produced using the parameter estimates obtained by the authors?

4. Can you provide estimates of the parameters of an EGARCH model that uses Handley's data updated to the end of 2011? The relevant series that you need to consider are: The grossed up series of with-credit returns to the Australian market portfolio, computed under assumption that the market values a one-dollar credit at 35 cents (Handley has not published these data in full but NERA have recreated them and you will be provided with the data that NERA have assembled); and, the bill return, which was calculated by rolling over three-month Treasury Notes. These series are the ones that McKenzie and Partington and NERA use.

5. What are the results for volatility from your amended EGARCH model?

6. Can you assess the statement made by McKenzie and Partington that 'where the returns are skewed the [sample mean] will be biased'(paragraph 10 of the 21st December 2011 equity market risk premium report)?

7. Can you assess the statements made by McKenzie and Partington about the mean, median and mode: '[In] large samples ... differences between the three measures of central tendency [will] be small' (paragraph 10 of the equity market risk premium report)?

2 Analysis

1. Is the EGARCH model prepared by McKenzie and Partington correctly specified?

The correct specification of the EGARCH(1,1) model, due to Nelson (1991), is:

$$r_t = \mu_t + h_t^{1/2} z_t, \;\; z_t \sim \text{i.i.d } N(0,1)$$

$$\log(h_t) = \mu_{\log(h)} + \beta \left(\log(h_{t-1}) - \mu_{\log(h)} \right) + g(z_{t-1})$$

where

$$g(z_{t-1}) = \theta z_{t-1} + \gamma \left(|z_{t-1}| - \sqrt{\frac{2}{\pi}} \right)$$

and r_t is the return to the market portfolio in excess of the return to a bill, μ_t is the conditional mean of the excess return, h_t is the conditional variance of the excess return, and it is assumed that z_t follows a Normal distribution with mean 0 and standard deviation 1. The parameters of the model, to be

estimated on the basis of the data, are μ_t, $\mu_{\log(h)}$, β, θ, and γ. Note that in principle μ_t can vary, but McKenzie and Partington assume that it is a constant, μ.

The specification given by McKenzie and Partington (2012) is incorrect. They give the second line above as:

$$\log(h_t) = \mu_{\log(h)} + \beta \log\left(h_{t-1} - \mu_{\log(h)}\right) + g(z_{t-1})$$

A comparison of their specification with that of Nelson's above indicates McKenzie and Partington have omitted two parentheses - an opening parenthesis after β and a closing parenthesis after h_{t-1}

Additional concerns about the specification of the model are addressed in the answer to question 5.

Appendix A shows the equivalence of the EGARCH(1,1) model, as intended by McKenzie and Partington (2012), with the original specification given by Nelson (1991).

2. Can you calculate the unconditional volatility of the excess return to the market portfolio that results from, or is implied by, the EGARCH parameter estimates that McKenzie and Partington provide and compare the value that you produce with the estimates that Brailsford, Handley and Maheswaran (2012) supply?

I have used the `rugarch` package (Ghalanos, 2012a) in the R environment for statistical computing and graphics (R Core Team, 2013)[1]. This package allows one to conveniently estimate the parameters of various GARCH models.

The specification used in `rugarch` is slightly different but equivalent, as shown in Appendix A. The corresponding specification for the EGARCH(1,1) model is

$$\log(\sigma_t^2) = \omega + \alpha_1 z_{t-1} + \gamma_1 \left(|z_{t-1}| - E(|z_{t-1}|)\right) + \beta_1 \log(\sigma_{t-1}^2)$$

[1] R was chosen because it is open-source and facilitates reproducible research. This report was produced using the `knitr` package (Xie, 2013), based on an underlying document that combines the text and R code used to produce the results, tables and figures. The `rugarch` package is one of several R packages that fit GARCH models. The R task view on Empirical Finance (Eddelbuettel, 2013) describes the facilities of the package: "The `rugarch` package can be used to model a variety of univariate GARCH models with extensions such as ARFIMA, in-mean, external regressors and various other specifications; with methods for fit, forecast, simulation, inference and plotting are provided too". Benchmarks are provided to show that `rugarch` produces results that are very similar to a commercial based product and to a published benchmark analysis.

and hence we have the following correspondences:

$$\begin{aligned} h_t &\equiv \sigma_t^2 \\ \mu_{\log(h)} &\equiv \frac{\omega}{1-\beta_1} \\ \theta &\equiv \alpha_1 \\ \beta &\equiv \beta_1 \\ \gamma &\equiv \gamma_1 \end{aligned}$$

Simulating 1,000,000 values of an EGARCH(1,1) process using the parameter estimates given by McKenzie and Partington (2012), gives a standard deviation of 0.426. Brailsford, Handley, and Maheswaran (2012), in contrast, report that the standard deviation of the return to the market portfolio in excess of the return to rolling over bills is, over the period 1833 to 2010, 0.168 - regardless of the assumption that one makes about the value that the market places on imputation credits. The difference between the two volatility values is quite pronounced and hints at a possible problem with the application of the EGARCH model by McKenzie and Partington.

3. Can you ascertain whether Figure 7 in the McKenzie and Partington review of the regime-switching framework report could reasonably have been produced using the parameter estimates obtained by the authors?

Figure 7 of McKenzie and Partington (2012) could not have been generated by an EGARCH model with the parameter estimates given in their Table 5. The average of $\log(\sigma_t^2)$ is given as $\exp(-1.7393/2) = 0.419$, implying that the expected value of σ_t is at least 0.419. However, the maximum volatility shown in Figure 7 (which can be inferred by digitising the graph using GetData Graph Digitizer 2.25, Federov, 2012) was 0.217. Digitising software extracts from a graph the data that would have been used to construct the graph (details and digitised data are given in Appendix D).

4. Can you provide estimates of the parameters of an EGARCH model that uses Handley's data updated to the end of 2011? The relevant series that you need to consider are: The grossed up series of with-credit returns to the Australian market portfolio, computed under assumption that the market values a one-dollar credit at 35 cents (Handley has not published these data in full

but NERA have recreated them and you will be provided with the data that NERA have assembled); and, the bill return, which was calculated by rolling over three-month Treasury Notes. These series are the ones that McKenzie and Partington and NERA use.

Using Handley's data provided by NERA, the parameters of the EGARCH(1,1) model were estimated using the `rugarch` package in R. The estimated parameters are given in Table 1. In addition, robust standard errors are given in Table 2.

	Estimate	Std.Error	$t-$value	$p-$value
μ	0.066	0.011	5.910	0.000
ω	-0.851	0.579	-1.472	0.141
α_1	0.042	0.117	0.362	0.717
β_1	0.765	0.154	4.972	0.000
γ_1	0.674	0.272	2.479	0.013

Table 1: Estimated parameters for EGARCH(1,1) model.

	Estimate	Std.Error	$t-$value	$p-$value
μ	0.066	0.014	4.807	0.000
ω	-0.851	1.271	-0.670	0.503
α_1	0.042	0.168	0.251	0.802
β_1	0.765	0.339	2.259	0.024
γ_1	0.674	0.564	1.195	0.232

Table 2: Estimated parameters for EGARCH(1,1) model with robust standard errors.

Table 3 provides a comparison of the parameter estimates given by `rugarch` with those given by NERA (2013)[2]. There are only slight differences, due to the different optimisation methods used by `rugarch` and SAS.

5. What are the results for volatility from your amended EGARCH model?

[2]See Appendix B for details of the equivalence of the parameter estimates given in Table 3 and the estimated EGARCH equation given in Equation B.1, page 109 of the NERA (2013) report.

	`rugarch` Estimate	NERA Estimate
μ	0.066	0.0660
ω	-0.851	-0.8356
α_1	0.042	0.0391
β_1	0.765	0.7707
γ_1	0.674	0.6501

Table 3: Comparison between Estimated parameters for EGARCH(1,1) model using `rugarch` and NERA (2013, page 109).

Using the estimated parameters, the calculated conditional standard deviation is plotted in Figure 1, together with the conditional standard deviations from the NERA (2013) report, based on the parameter estimates given in their report, and the conditional standard deviations from McKenzie and Partington's (2012) report, obtained by digitising the corresponding graph using GetData Graph Digitizer 2.25. The `rugarch` results are much more similar to the NERA results, and do not look at all like the McKenzie and Partington results. The differences between the rugarch results and the NERA results are very minor.

Indeed, the `rugarch` and NERA results are so similar that, aside from the first few years of each series it is difficult to see that Figure 1 plots three series and not two series. In contrast, the estimates that McKenzie and Parlington provide are much smoother than the estimates that NERA and I provide. In particular, they do not detect a substantial spike in volatility after the global financial crisis of 2008.

Figure 2 gives a QQ (Quantile-Quantile) plot of the residuals from the fitted EGARCH model. If the model is correctly specified, then the residuals should fall on a straight line in the plot. This is not the case, indicating that the residuals are not normally distributed. A better model is obtained by allowing the innovations to have a distribution with heavier tails such as a t-distribution. The best estimate of the degrees of freedom, ν, is 4.6, showing much heavier tails than for a normal distribution.

Figure 3 shows a Cumulative Sum chart of the mean-corrected volatility. In this graph, changes in the slope correspond to shifts in the mean of the underlying process[3]. The graph shows that just before 1960 the level of volatility increased. However, in the specified EGARCH model, the volatility, although autocorrelated, is assumed to be stationary.

A process is said to be autocorrelated if the current observation and at least one past observation are correlated with one another. A process is said to be weakly stationary if the first and second moments of the process do not depend on the data. Thus a process whose volatility drifts upwards over

[3]Details about how to interpret Cumulative Sum charts are given in Appendix C.

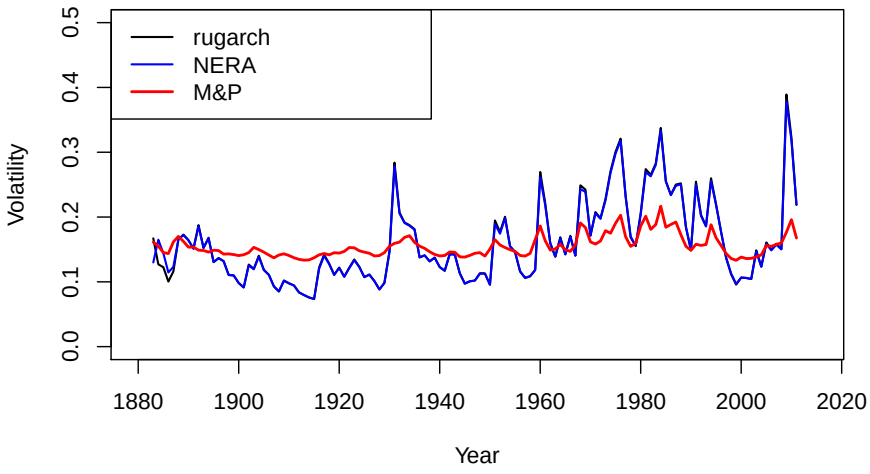

Figure 1: Comparison of volatility given by `rugarch`, that given by the NERA report and that given by McKenzie and Partington

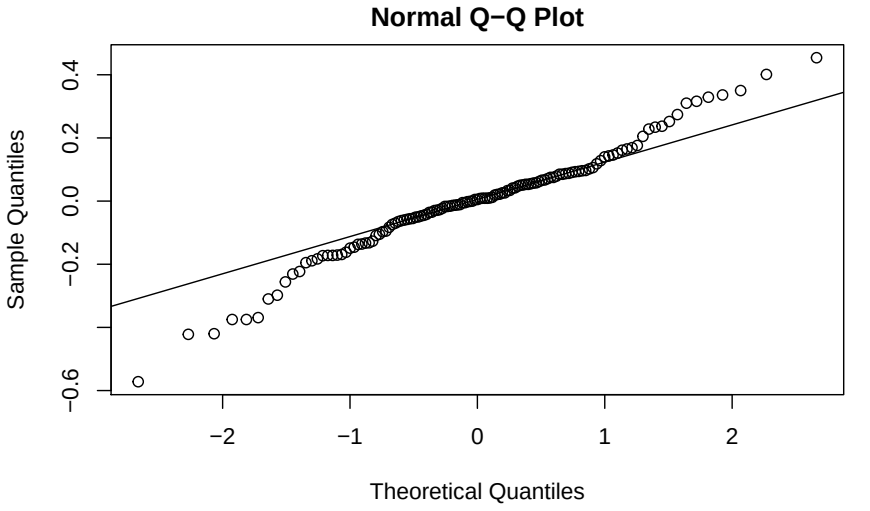

Figure 2: QQ plot of residuals for the EGARCH(1,1) model

time without displaying a tendency to revert to some long-run mean is said to be non-stationary. The EGARCH model that I presume that McKenzie and Partington intend to use rules out such behaviour.

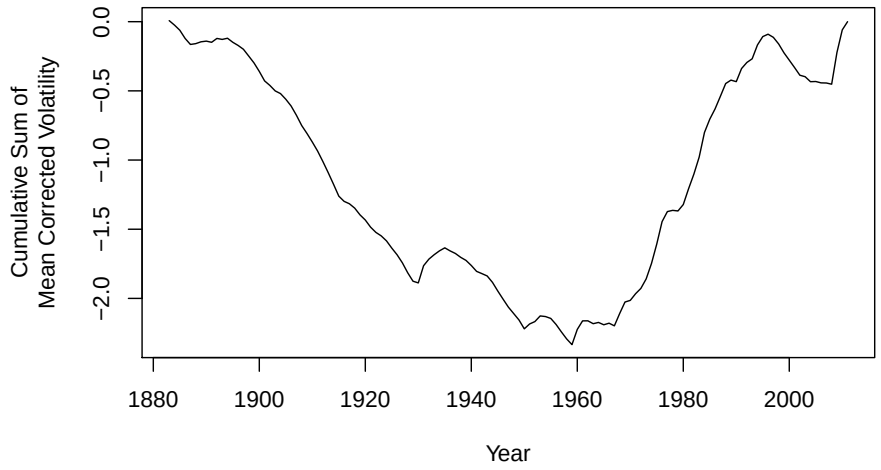

Figure 3: Cumulative Sum graph of the mean-corrected volatility

6. Can you assess the statement made by McKenzie and Partington that 'where the returns are skewed the [sample mean] will be biased'(paragraph 10 of the 21st December 2011 equity market risk premium report)?

The statement that McKenzie and Partington make is not correct. The sample mean is an unbiased estimator of the population mean, as long as the population mean exists, irrespective of whether the distribution is skewed or not.

If the distribution is symmetric, the population mean and the population median are identical. Although the sample mean is a more efficient estimator than the sample median, the sample median is a more resistant estimator in the presence of outliers.

The situation is more complicated when the distribution is skewed. Generally, but not universally, when the distribution is positively skewed the following inequalities hold:

$$\text{Population Mode} < \text{Population Median} < \text{Population Mean}$$

The implication is that there is a bias using the sample median to estimate the population mean.

7. Can you assess the statements made by McKenzie and Partington about the mean, median and mode: '[In] large samples ... differences between the three measures of central tendency [will] be small' (paragraph 10 of the equity market risk premium report)?

The statement that McKenzie and Partington make will only be correct for symmetric distributions. For non-symmetric distributions, the statement is not correct.

Consider a lognormal distribution (see, for example, Forbes et al. 2011, pp 131-134.) with parameters μ and σ, the mean and standard deviation of the logarithm of the data values. Then we have the following:

$$\begin{aligned} \text{Mean} &= \exp\left(\mu + \frac{1}{2}\sigma^2\right) \\ \text{Median} &= \exp(\mu) \\ \text{Mode} &= \exp(\mu)/\exp\left(\sigma^2\right) \end{aligned}$$

Clearly, no matter the size of the sample, the three population parameters will remain different. Figure 4 shows a simulation for 100,000 samples of size 200, where the log returns of an asset are independent and identically distributed as normal with mean 8% and standard deviation 20%, with the mode being estimated using kernal density methods. Note how both the distributions of the sample mode and sample median are shifted to the left relative to the distribution of the sample mean. The difference between the mean and the median of the simple returns is, on average, 2.2% which relative to the population mean of the excess returns to the market portfolio is obviously economically significant.

The MRP is the difference between the mean (not the median) return to the market portfolio and the risk-free rate. Using the sample median of a series of returns to the market portfolio in excess of some measure of the risk-free rate to estimate the quantity can lead to bias–contrary to what McKenzie and Partington assert.

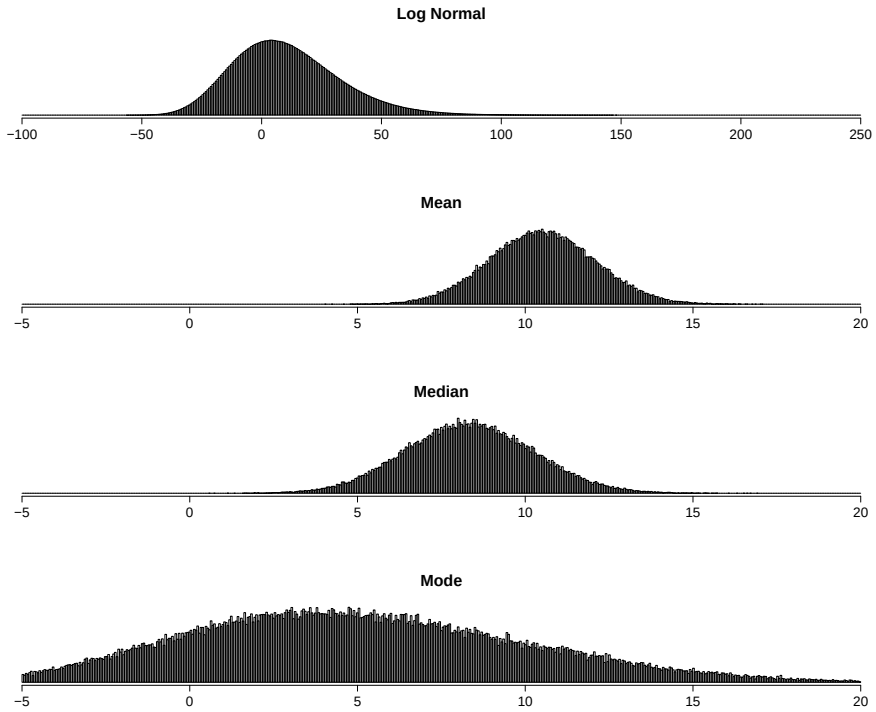

Figure 4: Simulated lognormal data and distributions of means, medians and modes of simple returns. Note that a different scale has been used for the individual results in the top panel, compared to the bottom three panels.

3 Conclusions

Based on my review I make the following conclusions:

- The EGARCH specification given by McKenzie and Partington (2012) is not correct. In addition, residuals from the model are clearly non-normal, and the volatility seems to have undergone a step change just prior to 1960.
- The average volatility based on McKenzie and Partington's parameter estimates is approximately 0.426. This is a very high result. Brailsford, Handley, and Maheswaran (2012), in contrast, report that the standard deviation of the return to the market portfolio in excess of the return to rolling over bills is, over the period 1833 to 2010, 0.168 - regardless of the assumption that one makes about the value that the market places on imputation credits.
- Figure 7 of McKenzie and Partington (2012) does not match the parameter estimates given in their Table 5.
- I have used `rugarch` to provide updated parameter estimates for the EGARCH(1,1) model. These parameter estimates give volatility results very similar to those given by NERA (2013). However, the results are not at all similar to the McKenzie and Partington (2012) results.
- The sample mean is unbiased for the population mean, as long as the population mean exists, irrespective of the skewness of the population.
- There is no reason for the mean, median and mode to be the same for large samples if the distribution is skewed.

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A A comparison of EGARCH specifications

Following Engle (1982), for each time period let ξ_t be the model's prediction error and σ_t^2 be the variance of ξ_t given information at time t. Engle's ARCH model is given by

$$\xi_t = \sigma_t z_t, \quad \sigma_t^2 = \alpha_0 + \sum_{k=1}^{m} \alpha_i z_{t-k}^2$$

where z_t is independent and identically distributed with mean zero and standard deviation 1, $\alpha_0 > 0$, and $\alpha_k \geq 0$ for $k > 0$. In addition, the coefficients must satisfy some regularity conditions to ensure that the unconditional variance of ξ_t is finite (Tsay, 2010, p.116).

Nelson (1991) introduced the EGARCH model. His equations were:

$$\ln(\sigma_t^2) = \alpha_t + \sum_{k=1}^{\infty} \beta_k g(z_{t-k}) \tag{1}$$

$$g(z_t) = \theta z_t + \gamma \left(|z_t| - E(|z_t|) \right) \tag{2}$$

and a more parsimonious model than equation (2):

$$\ln(\sigma_t^2) = \alpha_t + \frac{(1 + \psi_1 L + \ldots \psi_q L^q)}{(1 - \Delta_1 L - \ldots \Delta_p L^p)} g(z_{t-k}) \tag{3}$$

where L is the backshift operator where

$$L z_t = z_{t-1}$$

and

$$L^q z_t = z_{t-q}$$

with q a positive integer.

The EGARCH(1,1) model corresponds to $\alpha_t \equiv \alpha$ and $q = 0$ and $p = 1$ and hence Equation (3) becomes:

$$\begin{aligned}
\ln(\sigma_t^2) &= \alpha + \frac{1}{(1 - \Delta_1 L)} g(z_{t-1}) \\
\Rightarrow (1 - \Delta_1 L) \ln(\sigma_t^2) &= (1 - \Delta_1 L)\alpha + g(z_{t-1}) \\
\Rightarrow \ln(\sigma_t^2) - \Delta_1 \ln(\sigma_{t-1}^2) &= (1 - \Delta_1)\alpha + g(z_{t-1}) \\
\Rightarrow \ln(\sigma_t^2) &= (1 - \Delta_1)\alpha + g(z_{t-1}) + \Delta_1 \ln(\sigma_{t-1}^2) \\
&= (1 - \Delta_1)\alpha + \theta z_{t-1} + \gamma \left(|z_{t-1}| - E(|z_{t-1}|) + \Delta_1 \ln(\sigma_{t-1}^2) \right)
\end{aligned}$$

The `rugarch` model has the general specification (Ghalanos, 2012b):

$$\ln(\sigma_t^2) = \left(\omega + \sum_{j=1}^{m} \zeta_j v_{jt} \right) + \sum_{j=1}^{q} \left(\alpha_j z_{t-j} + \gamma_j \big(|z_{t-j}| - E(|z_{t-j}|) \big) \right) + \sum_{j=1}^{p} \beta_j \ln(\sigma_{t-j}^2)$$

where v_j's are external regressors. In the EGARCH(1,1) model there are no external regressors and $q = 1$ and $p = 1$, leading to the equation

$$\ln(\sigma_t^2) = \omega + \alpha_1 z_{t-1} + \gamma_1\big(|z_{t-1}| - E(|z_{t-1}|)\big) + \beta_1 \ln(\sigma_{t-1}^2)$$

and hence the Nelson EGARCH(1,1) model and the `rugarch` specification are identical where

$$\begin{aligned}(1-\Delta_1)\alpha &\equiv \omega \\ \theta &\equiv \alpha_1 \\ \gamma &\equiv \gamma_1 \\ \Delta_1 &\equiv \beta_1\end{aligned}$$

The corrected version of the specification provided incorrectly by McKenzie and Partington is

$$r_t = \mu_t + h_t^{1/2} z_t,\ z_t \sim \text{i.i.d } N(0,1)$$

$$\log(h_t) = \mu_{\log(h)} + \beta\big(\log(h_{t-1}) - \mu_{\log(h)}\big) + g(z_{t-1})$$

where

$$g(z_{t-1}) = \theta z_{t-1} + \gamma\left(|z_{t-1}| - \sqrt{\frac{2}{\pi}}\right)$$

This can be rewritten as

$$\begin{aligned}\log(h_t) &= \mu_{\log(h)} - \beta\mu_{\log(h)} + \beta\log(h_{t-1}) + \theta z_{t-1} + \gamma\left(|z_{t-1}| - \sqrt{\frac{2}{\pi}}\right) \quad (4)\\ &= \mu_{\log(h)}(1-\beta) + \beta\log(h_{t-1}) + \theta z_{t-1} + \gamma\left(|z_{t-1}| - E(|z_{t-1}|)\right)\end{aligned}$$

since

$$E(|z_{t-1}|) = \sqrt{\frac{2}{\pi}}$$

when z_t follows a standard normal distribution. Again, this is equivalent to the Nelson EGARCH(1,1) model where

$$\begin{aligned}(1-\Delta_1)\alpha &\equiv \mu_{\log(h)}(1-\beta) \\ \theta &\equiv \theta \\ \gamma &\equiv \gamma \\ \Delta_1 &\equiv \beta\end{aligned}$$

Finally, the equivalence between the corrected specification due to McKenzie and Partington (2012) and the `rugarch` specification is given by

$$\begin{aligned} \mu_{\log h} &\equiv \frac{\omega}{1-\beta} \\ \theta &\equiv \alpha_1 \\ \beta &\equiv \beta_1 \\ \gamma &\equiv \gamma_1 \end{aligned}$$

B NERA's Equation B.1 and Implied Parameter Estimates in Table 3.

Equation (4) in Appendix A can be rewritten as follows:

$$\begin{aligned} \log(h_t) &= \mu_{\log(h)} - \beta\mu_{\log(h)} + \beta\log(h_{t-1}) + \theta z_{t-1} + \gamma\left(|z_{t-1}| - \sqrt{\frac{2}{\pi}}\right) \\ &= \mu_{\log(h)}(1-\beta) - \gamma\sqrt{\frac{2}{\pi}} + \beta\log(h_{t-1}) + \theta z_{t-1} + \gamma(|z_{t-1}|) \\ &= \omega - \gamma\sqrt{\frac{2}{\pi}} + \beta\log(h_{t-1}) + \theta z_{t-1} + \gamma(|z_{t-1}|) \end{aligned}$$

NERA (2013, Equation B.1, page 109) give the estimated EGARCH model as:

$$\begin{aligned} r_t &= 0.0660 + h_t^{1/2} z_t \qquad z_t \sim \text{NID}(0,1) \\ \log(h_t) &= -1.3543 + 0.7707\log(h_{t-1}) + 0.6501|z_{t-1}| + 0.0391 z_{t-1} \end{aligned}$$

and hence

$$\begin{aligned} \mu &= 0.0660 \\ \alpha_1 = \theta &= 0.0391 \\ \beta_1 = \beta &= 0.7707 \\ \gamma_1 = \gamma &= 0.6501 \\ \omega - \gamma\sqrt{\frac{2}{\pi}} &= -1.3543. \end{aligned}$$

Therefore,

$$\begin{aligned} \omega &= -1.3043 + \gamma\sqrt{\frac{2}{\pi}} \\ &= -1.3043 + 0.6501\sqrt{\frac{2}{\pi}} \\ &= -1.3043 + 0.5187 \\ &= -0.8356. \end{aligned}$$

C Cumulative Sum Chart of mean-corrected volatility.

Cumulative Sum charts (see, for example, Box and Luceño, 1997, pp.75–78.) have long been used in quality control and other applications to determine changes in the mean level of processes. Some details of how to interpret Figure 3 are given below.

Let v_t be the estimated volatility at time t, with $\overline{v}$ the average volatility. The cusum at time t is given by

$$c_t = \sum_{i=1}^{t} (v_i - \overline{v}),$$

the cumulative sum of the mean corrected volatiliy. A cusum graph is a line-graph of c_t versus the time-period t.

Consider two time points r and t. The slope of the cusum graph is given by

$$\begin{aligned} \frac{c_t - c_r}{t - r} &= \frac{\sum_{i=1}^{t}(v_i - \overline{v}) - \sum_{i=1}^{r}(v_i - \overline{v})}{t - r} \\ &= \frac{1}{t - r} \sum_{i=r+1}^{t} v_i - \frac{(t - r)\overline{v}}{t - r} \\ &= \overline{v}_{r+1:t} - \overline{v} \end{aligned}$$

where $\overline{v}_{r+1:t}$ is the mean volatility from period $r + 1$ to t. The following conclusions apply:

- For periods when the slope of the cusum is zero, the mean volatility is equal to the overall mean volatility.
- For periods when the slope of the cusum is positive, the mean volatility is greater than the overall mean volatility.
- For periods when the slope of the cusum is negative, the mean volatility is less than the overall mean volatility.
- Changes in the level of the mean volatility correspond to changes in the slope of the cusum graph.

Figure 3 shows a marked change in the slope just before 1960. The overall mean volatility is 0.159, but prior to the change in slope the mean volatility was 0.129, and after the change in slope the mean volatility was 0.204, corresponding to a 58% increase.

D Digitisation Data

GetData Graph Digitizer 2.25 is a program for digitising graphs and plots. It allows the capture of the (x,y) co-ordinates from line graphs where the original data is not available. The algorithm used was "Auto trace line", where a starting point on the line is selected and the program traces the line, stopping at its end, and giving a series of co-ordinates on the line.

Figure 7 of Mckenzie and Partington (2012) was digitised using GetData Graph Digitizer 2.25. Based on the co-ordinates provided by the program, linear interpolation was used to give volatility values for each year from 1883 to 2011, and these values were used in the subsequent analysis. The reconstructed data are given in Table 4.

Year	Volatility	Year	Volatility	Year	Volatility
1883	0.161	1926	0.144	1969	0.184
1884	0.155	1927	0.140	1970	0.162
1885	0.145	1928	0.141	1971	0.158
1886	0.144	1929	0.145	1972	0.163
1887	0.162	1930	0.155	1973	0.179
1888	0.170	1931	0.159	1974	0.175
1889	0.162	1932	0.161	1975	0.190
1890	0.153	1933	0.169	1976	0.203
1891	0.154	1934	0.171	1977	0.170
1892	0.149	1935	0.161	1978	0.155
1893	0.148	1936	0.155	1979	0.159
1894	0.146	1937	0.152	1980	0.186
1895	0.149	1938	0.146	1981	0.201
1896	0.148	1939	0.142	1982	0.181
1897	0.143	1940	0.140	1983	0.188
1898	0.143	1941	0.141	1984	0.217
1899	0.142	1942	0.146	1985	0.184
1900	0.141	1943	0.146	1986	0.188
1901	0.142	1944	0.139	1987	0.192
1902	0.145	1945	0.138	1988	0.173
1903	0.153	1946	0.141	1989	0.155
1904	0.150	1947	0.144	1990	0.149
1905	0.146	1948	0.145	1991	0.158
1906	0.141	1949	0.140	1992	0.156
1907	0.137	1950	0.151	1993	0.158
1908	0.141	1951	0.165	1994	0.188
1909	0.143	1952	0.157	1995	0.168
1910	0.141	1953	0.153	1996	0.156
1911	0.137	1954	0.150	1997	0.144
1912	0.135	1955	0.147	1998	0.136
1913	0.133	1956	0.141	1999	0.133
1914	0.134	1957	0.140	2000	0.138
1915	0.137	1958	0.144	2001	0.136
1916	0.142	1959	0.165	2002	0.136
1917	0.144	1960	0.186	2003	0.138
1918	0.142	1961	0.163	2004	0.142
1919	0.145	1962	0.149	2005	0.156
1920	0.144	1963	0.151	2006	0.155
1921	0.147	1964	0.158	2007	0.158
1922	0.153	1965	0.150	2008	0.160
1923	0.153	1966	0.147	2009	0.177
1924	0.148	1967	0.157	2010	0.196
1925	0.146	1968	0.191	2011	0.168

Table 4: Reconstructed Data for Figure 7 of McKenzie and Partington (2012).

E Neil Diamond CV

Curriculum Vitae
Neil Diamond July 2013

Full Name:	Neil Thomas Diamond
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*, **23**:2, 39–54.

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. Deppeler, J., Moore, D., Diamond, N. (2013). "Public School-Based Intervenetions for Adolescents and Young Adults with an Autism Spectrum Disorder: A Meta-Analysis," Accepted for publication in *Review of Educational Research*.

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., and 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.*

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 the South Australian Electricity Distributors.

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*