Another Pioneering Use of DFA: New Zealand Earthquake Commission

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Abstract: The New Zealand Earthquake Commission (EQC) started using DFA (Dynamic Financial Analysis)[1] in 1994 and has used DFA commercially ever since. EQC was one of the pioneers in the application of DFA to the insurance industry. Other pioneering users at the same time are described in four papers in the Casualty Actuarial Society Forum, Spring, 1996. The development of models for EQC has not previously been fully described in the literature.[2] This paper describes the development of DFA models for EQC from the viewpoint of the user.

DFA BACKGROUND

A major theoretical basis for DFA was published in English in 1969: *Risk Theory - the Stochastic Basis of Insurance* by R.E. Beard et al.[3] It provided the theory and methodology for measuring total risk and return of insurance businesses.

Some years passed after this book was published before its methods were applied. Computers at that time were far too slow to carry out the number of simulations required, particularly when dealing with catastrophe risks where distributions typically have a long tail. The same problem also arose with the simulation of asset risk, where again and again firms have discovered to their chagrin that the probability distribution of their asset values has an unexpectedly fat tail.

Stochastic modelling was clearly needed to model total risk and return:

- Relationships between the various risks affecting insurance businesses are complex and the relationship between total risk and return cannot in general be calculated through solvable algorithms.
- Over a defined period of years many different sequences of events can occur. Assessing the outcome at the end of the multi-year period requires that all likely sequences be taken into account, according to the probability of each sequence. No method of summing the possible pathways exists, apart from simulation.

Monte Carlo modelling provided the solution. By using a large number of simulations, 100,000 or even more, it was possible to sufficiently reduce the confidence limits so as to make the results reliable. And it was possible to run these large numbers of simulations within a reasonable time - hours rather than days.

DFA using large numbers of simulations was starting to be used commercially about 1994. A second important book: *Practical Risk Theory for Actuaries* by Daykin, Pentikainen, and Pesonen was

1 The term "Dynamic Financial Analysis" has been largely superseded by the term "Capital Modelling." The earlier term is used here because it was current during the time of the events described in this article.

2 David Middleton provides an outline of the development amongst other modelling in Middleton (2002)

3 Beard (1969)

published by Chapman and Hall at the end of 1993.[4] This covered much the same material as the earlier Beard work of 1969 in a slightly more user-friendly, albeit less elegant, form.

In 1994 several firms were pioneering the use of DFA for commercial purposes. This innovation was described in several papers in the Casualty Actuarial Society *Forum*, Spring, 1996:[5]

- within Liberty Mutual; authors Douglas M Hodes et al.[6];
- by Tillinghast – Towers - Perrin for RenaissanceRe; authors Stephen P. Lowe and James N. Stanard[7];
- the *MIDAS model*, client and modellers unstated; authors Steven Thoede and Janet Haby[8];
- by INSTRAT for Insurance Corporation of British Columbia (ICBC); authors Rodney E. Kreps and Michael M. Steel.[9]

In all these four documented cases, the work was novel in that it modelled the overall financial statements of insurance businesses to forecast risk and return over multi-year time horizons, and it did so fast enough to be of commercial use.

At about the same time as that modelling was being developed by these firms, the Subcommittee on Dynamic Financial Models of the Casualty Actuarial Society was working on DFA. Its purpose was to:

…to discuss and provide guidance on the important issues and considerations that confront actuaries when designing, building or selecting dynamic financial models of property-casualty risks.[10]

In addition to providing sound advice for modellers and users of DFA, the Sub-Committee report in September 1995 contained a useful bibliography of the prior literature.

THE COMMISSION —- EQWD BECOMING EQC

In 1991, on becoming Chair of the Earthquake and War Damage Commission (EQWD), I was given the task of leading a reform of the Commission.

The reform was initiated by the new Minister in Charge of the Commission (Hon Doug Kidd, now Sir Douglas) and the Treasury. The basic structure of the Commission was retained, but with major change in the cover provided:

- only domestic property was covered, with commercial property phased-out;
- the cover was changed from an indemnity basis to repair or replacement;

4 Daykin (1993).

5 https://www.casact.org/pubs/forum/96spforum/

6 Hodes (1996)

7 Lowe (1996)

8 Thoede (1996)

9 Kreps (1996)

10 Van Slyke (1995) p1

- caps were imposed on cover at $100,000[11] for buildings and $20,000 for contents, both exclusive of GST[12]
- tsunami was added to the hazards covered
- war damage was no longer covered, and consequentially the name of the institution changed to the Earthquake Commission (EQC).

The changes were driven by a very competent board, including the Deputy Chair Trevor Roberts. David Middleton came in as General Manager and brought strong insurance expertise.[13]

Of significance in the development of DFA modelling were the Commission's reinsurance and investment policies.

Its reinsurance programme was in 1991 believed to be the largest catastrophe program in the world with NZD 1 billion cover (in excess of NZD 1 billion). The cover was placed by a consortium of three of the world's leading reinsurance brokers, and led by Lloyd's underwriters together with Swiss Re.

Government policy required EQC to follow an archaic investment policy. Apart from cash, all funds were invested in New Zealand Government stock. This policy was a relic of the quite recent time when almost all the funds held by the Crown[14] and Crown agencies were centralised and pooled. Similarly, the management of risk, to the extent that it was managed at all, was mostly centralised.

Because nearly all the Commission's assets were invested in New Zealand government stock, the Crown had effectively retained much of the risk brought to it by EQC's cover of catastrophes. The economic effect of EQC realising government stock in order to pay claims would be essentially the same as government issuing new stock. This risk was managed only to the extent that reinsurance was purchased.

Moreover, by law the Crown guarantees payment of "the liabilities of the Commission."[15] The Crown thus carried the risk of liabilities exceeding assets. This risk was open-ended and unmanaged.

A change in the external environment also had an impact on the Commission and was causing great concern. The turmoil in the Lloyd's insurance market, as the LMX (London market excess) spiral of the late 1980s collapsed, led to a reduction in the reinsurance capacity available to the Commission.

The Board of the Commission sought strategies to deal with its new situation. It commissioned Frank Russell Company Pty to report on investment policy, and specifically on asset allocation strategy. The report was received in December 1992. It was written by Prof Craig Ansley, then

11 All $$$ are NZD, worth 66 US cents in 20 Aug 2018

12 GST is a value-added tax

13 Mrs Demetra Kennedy as Acting General Manager had held the organisation together over a difficult time of uncertainty.

14 In NZ as in the UK, the Central Government is commonly referred to as "the Crown" when it acts financially or legally.

15 Earthquake Commission Act (1993), s16.

NZI Professor of Finance at Auckland University.

The report was wide reaching. It was based on a model of liabilities developed by Craig Ansley.[16] He pointed out that with expected losses at $71 million exceeding premiums at $69 million, we could not expect funds to accumulate.

In a letter to the Commission dated 24 February 1993, he elaborated on this statement. He pointed out that every elementary textbook on the Theory of Risk shows that if premiums net of expenses is equal to expected losses, and no income is earned on investments, '… (eventual insolvency) is *certain'* [his emphasis]. He calculated that under the existing regime with dividends and fees of $150 million being paid to the Crown, and a premium rate of $0.050 per $100, the approximate probability of ruin was 92%.

This struck terror into our hearts.

In parallel with our consideration of investment strategy and premium rates, we were also investigating what changes should be made in reinsurance strategy in the light of the reduced capacity available in the market.

Naively, I asked the question: how do we know we are getting the best bang for our buck from reinsurance? The answers from our advisers in the industry were not measures of value. Most were qualitative in nature: 'based on your objectives', 'protection providing comfort', 'sleep easy', etc. The only quantitative responses proposed meeting PML's at minimum cost, with PML's based on modelling of scenarios.

Craig Ansley advised that it had quite recently become practical to quantify total risk and return through modelling. The theory had been around for some time[17] but faster computers now enabled modelling to be done in reasonable time. Thus, this modelling had become commercially practical.

The basis was stochastic modelling using the Monte Carlo method. The tools were the same as he had already used in building the loss model for his previous report. But these tools had hardly as yet been used in the insurance industry.

At about the same time, the Finance Manager for EQC, Paul Martin, visited a technical agency of one of our reinsurance brokers: INSTRAT, then owned by Sedgwick Payne, and located in Seattle. Several key people were involved: Mr Donald Paterson who had a deep understanding of the nature of risk and how it could be managed, Dr Rodney Kreps who had published seminal papers on the pricing of reinsurance, and Mr Michael Steel who was an accomplished modeller.

Paul Martin reported back to us that INSTRAT was able to give us measures of what insurance programme would be optimal for our situation. The management and board of EQC were

16 Ansley (1993)

17 As expounded in Beard (1969).

sceptical, but Paul was quite insistent. Eventually we opened dialogue with INSTRAT and they too offered us modelling of our total risk and return.

Both Frank Russell and INSTRAT told us that they knew of nobody in the world currently using these techniques, apart from the Insurance Corporation of British Columbia for whom INSTRAT was building a model.

EQC decided to engage the firms to each build a model of EQC total risk and return. Using Monte Carlo modelling, each model was to some extent a "black box" in that their internal logical steps could not be sufficiently analysed to determine whether the results were trustworthy. The only way to effectively check on the results of the model was to have parallel models built independently but drawing on the same data. If the two models produced similar results, one could rely upon them. If the results differed, there would be an opportunity to explore within the models the reasons for the difference. We did of course also test the models by setting various parameters, to 0,1, or perhaps 1000 (according to the limits of the range of the parameter), and examining whether the results were plausible.

PROCESS OF DEVELOPING MODELS

The two models being developed were similar in some respects:

- Both used stochastic modelling based on the Theory of Risk.
- Both were to be based on a model of the Commission's earthquake losses already developed by Prof. Craig Ansley.
- Both used the same formula for reinsurance pricing as published by Dr. Rodney Kreps.[18]
- Both modelled the same financial flows and stocks of the Commission and used the same financial structure.
- Both had as outputs the risk and return of different strategies.

But in other respects, the models were different:

- The Frank Russell model was written in Visual Basic and was hardcoded, so that any changes in parameters had to be made by the programmer.
- The INSTRAT model was written in C^{++}. It had an interface which allowed EQC users to vary some of the parameters.
- The Frank Russell model was able to explore different financial structures, and the INSTRAT model allowed more reinsurance options to be evaluated.

Despite their differences, each model was capable of representing the total risk and return of EQC, and had the ability to optimise strategies by varying key parameters.

Modelling was mostly carried out over time-horizons of 5 or 20 years. The primary measure of risk was probability of ruin: i.e. EQC exhausting its capital and hence calling upon the Crown to support payment of claims. Other risk measures were also used as confidence in the modelling developed.

18 See Kreps (1990).

At first there were considerable differences in the output of the two models. These arose partly because of different understandings of the rules inherent in the Commission's structure. The Commission's business structure was prescribed by an Act of Parliament and differed significantly in many respects from the structure of commercial insurers.

In order to determine the reasons for differences in the outputs from the two initial models, a workshop meeting was held in Seattle with both sets of modellers and me participating. We followed through the way that each model depicted EQC structure and the basic logic of the models. We examined the differences in results and resolved differences in interpretation.

The models when revised produced reasonably consistent results and were then again fine-tuned in to further improve consistency.

Output from the models

The first major output was a report from Frank Russell based on their model. It dealt with:

- solvency and probability,
- the Crown underwriting fee, dividend and taxation,
- factors affecting the probability of ruin,
- the solvency limit, and
- the financial outlook.

The model tested variations such as the size of the *Fund* (essentially the capital or the surplus of the Commission), the fees charged by the Crown, asset allocation, and economic growth. The effect of these variations on the probability of ruin were indicated.

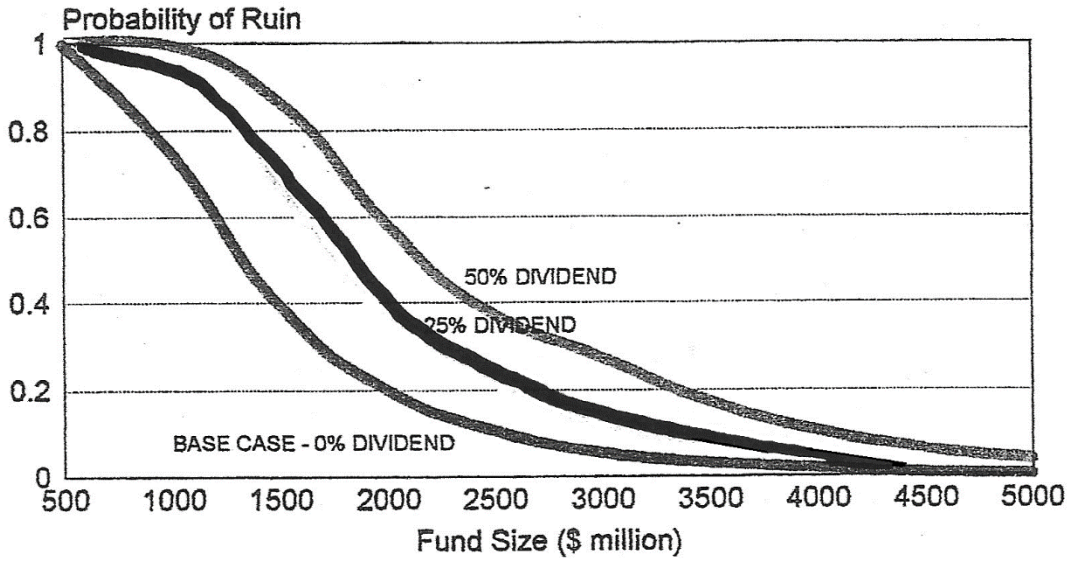
The report[19] included simple but powerful charts of which one example was Figure 14:

19 Ansley (1994)

Figure 14

PROBABILITY OF RUIN

Solvency Limit = Initial Fund Size



In this report, and in the earlier loss distribution report,[20] Craig Ansley gave several warnings which proved prescient in the light of the Christchurch earthquakes (these are discussed below).

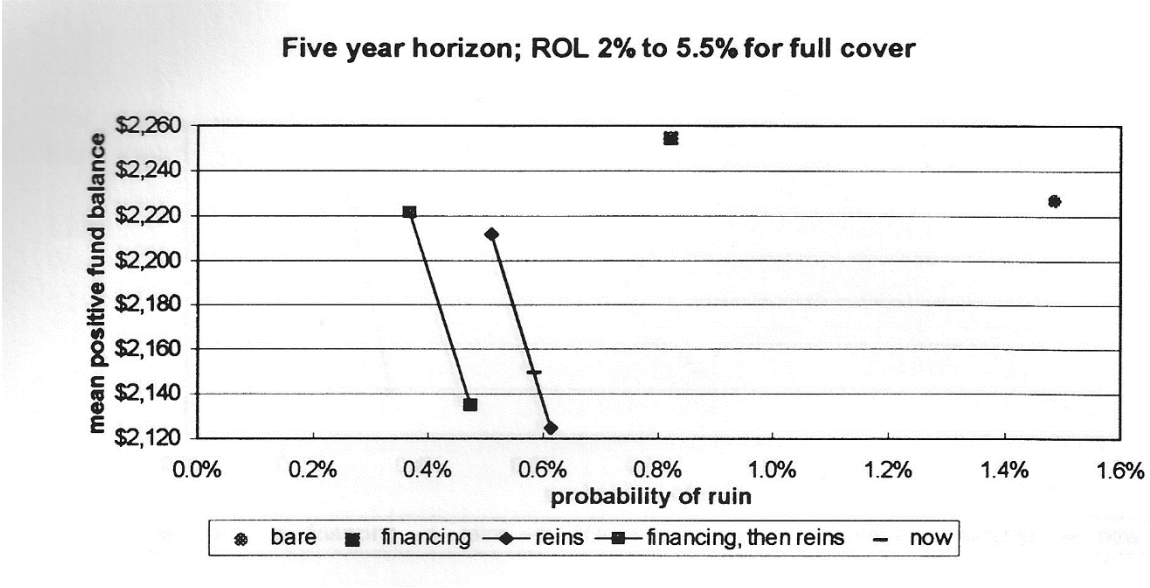
The INSTRAT model was used initially to optimise the existing conventional reinsurance program. The Commission was using all the capacity it could obtain from creditworthy reinsurers across the world at a reasonable price. The structure of this program was somewhat constrained. While moving the attachment point up or down by changing the deductible was a possibility, at high levels a minimum rate-on-line applied, despite the reduced risk. At low levels the rate-on-line increased quite sharply. Modelling indicated the optimal structure of the program.

One of the conclusions from the modelling was that multi-year covers would provide better value than single year covers at comparable rates. The advice was that such covers were difficult to obtain in the market at that time at a reasonable price. In subsequent years EQC used multiple year covers extensively once underwriters were prepared to write them.

The available capacity of traditional reinsurance was limited. It was less than the commission had purchased in the past. New products were at the time being developed in the finance and reinsurance markets in response to the shortage of traditional reinsurance capacity. We did not consider that these had reached sufficient maturity to be available for consideration by EQC. The INSTRAT model was used to explore other options of protection — especially post–event financing. This was the most significant form of alternative protection available at that time.

20 Ansley (1993)

One example is shown below in a chart provided in an INSTRAT report.



The explanation read: "Category 4 uses a combination of financing and a reinsurance with the financing paying first. This is a very interesting result because for each reinsurance ROL the fund size is slightly greater than option 2, and the probability of ruin is about 20% smaller. For this reason, we believe it is reasonable to take the view that option 4 dominates option 2 and should therefore be preferred."

In the event, EQC did not use post-event financing. The Treasury considered that any borrowing post-event should be done by the Crown itself, and that no prior arrangements were necessary for such borrowing. However, the analysis was of great value in demonstrating to the Treasury the level of risk to which it was exposed and the need to reduce the fees the Crown charged EQC (see below).

So, we explored the modelling of financing and reinsurance, and on the journey learnt about statistical dominance.

Use of the models

It took until well into 1994 before the results of the models were reasonably consistent. In the meantime, however, the Commission gained a much deeper understanding of its financial and risk structure, and the drivers of its business.

As soon as the models were developed, they were used by EQC in two specific ways:

- as a basis for negotiations with the Treasury and ministers, especially regarding investment policy and fees.
- In determining reinsurance strategy and purchases.

The Frank Russell model was used by EQC mainly as the basis of advice on its investment policy. It gave a strong quantitative basis for the Commission's discussions with The Treasury, who took some time to take any interest in the modelling, or show appreciation of its value.

The INSTRAT model was used in devising reinsurance strategy and tactics. From the first runs it gave a clear indication of the risk and return of various protection options.

Because the Frank Russell model was hardcoded, it was operated entirely by Craig Ansley and his staff. The output to EQC was in written reports.

The INSTRAT model was different in that it was designed to run on EQC laptops as well by INSTRAT itself. Considerable work was necessary to make the model user-friendly. I have copies of emails between Rodney Kreps and me discussing how version 13 of the INSTRAT model could be improved. Later, when a Windows interface was developed, the model became much easier to use.

The Commission also received reports from INSTRAT on protection strategies based on model results.

In 1994 I was able to say in the EQC Annual Report to Parliament that: "we have now developed a corporate financial model which enables changes in policy to be tested and their effect on EQC survival to be measured."[21]

Since then, DFA modelling has been continually used by EQC, sourced directly as well as through its reinsurance brokers.

VALUE OF THE MODELS

The models gave EQC board and management a much clearer appreciation of the risk and return of different strategies.

Prior to having model results, strategies were based on philosophical principles rather than hard numbers. Through the modelling, the risk brought to the Crown by EQC became more visible. This contributed to the decision by the government in 1995 not to require EQC to pay tax or dividends.[22]

In reinsurance purchases, modelling soon became routine. Initially it was done using the model constructed for EQC by INSTRAT, and later through modelling carried out by EQC's brokers as the basis of their advice. ReMetrica was used as a matter of course.

In 1999 EQC went to tender in for disaster risk and financial modelling. The tender was won by Aon who subsequently provided a model 'Minerva' to EQC.

The people involved

Craig Ansley continued to provide advice to EQC from Frank Russell after this modelling work was done.

21 See Annual Report of the Earthquake Commission 1993 – 1994, p8,

22 See Annual Report of the Earthquake Commission 1996-1997, p29

Two of the people involved in developing the INSTRAT model moved in 1996 to join Greig Fester, reinsurance brokers in London. Donald Paterson and Michael Steel developed there the modelling platform called ReMetrica. This took into account their earlier work, but had much greater functionality, and was much more user-friendly.

Greig Fester merged with Benfield Ellinger, and later with Aon. For many years this firm and its successors were lead broker or sole broker for the EQC reinsurance program. In this role they used ReMetrica extensively in providing advice on reinsurance structures and purchases.

Don Paterson and Michael Steel also led the use of DFA modelling by insurers and reinsurers worldwide. I retired from EQC in 1995, and later became associated with Greig Fester. My role was assisting with the application of ReMetrica to particular projects and demonstrating to insurers and reinsurers how DFA modelling could enable them to make better decisions.

CHRISTCHURCH EARTHQUAKE[23]

EQC was severely challenged by the Canterbury series of earthquakes commencing on 4th September 2010. It is natural to ask whether the losses experienced in these earthquakes were consistent with modelled results.

In one sense these earthquakes were not a test of the models. The model did not seek to measure the effect of single events or a series of events over a short period of time. The models dealt with periods of time of five years, 20 years or longer. Single events were modelled as they had been in the past, by the use of scenarios.

Nevertheless, the magnitude of the losses experienced in Christchurch was substantially more than the catastrophe models underlying initial DFA models had envisaged. This was so even after taking account of increases in building costs, higher building standards adding costs, and the increase in the number of dwellings.

The most important reason for the difference was that the Canterbury sequence of earthquakes was clearly a "black swan" occurrence.[24] The Greendale Fault event of September 2010 that initiated the Canterbury Sequence may have a recurrence interval of around 5300 years,[25] or it may not have moved for 20 to 30,000 years prior to 2010.[26] In either case, the recurrence interval is far beyond the time horizon over which insurers measure risk (and beyond the planning horizon for society itself!).

23 Referred to more formally as the Canterbury Earthquakes

24 As a point of interest, all the wild swans in New Zealand are black - Cygnus atratus.

25 Villamorl p21

26 Hornblow (2016), abstract. See also Van Dissen (2015) and Guiang (2014)

A BRANZ bulletin has summarised other unusual features thus[27]:

"The [Canterbury] series was unique in New Zealand and the world because:

- there were several major events in a short timeframe.
- the quakes were centred close to each other.
- there were high vertical accelerations.
- there was widespread liquefaction."

In its work about the time of the development of the models, EQC had explored the issue of multiple events, especially "after-shocks." The context was primarily the "hours clause" in reinsurance contracts. Perhaps we were lulled into false complacency by a belief that because the magnitude of after-shocks should reduce according to the Gutenberg–Richter law, the intensity of shaking and the damage caused by after-shocks would reduce similarly.

While the magnitude of the events subsequent to 4th September 2010 reduced generally as the Gutenberg–Richter law would predict, their peak ground accelerations did not. The extraordinarily high vertical accelerations of the 21 February event were an unexpected phenomenon and were due largely to the local geological structure.

The likelihood of liquefaction was appreciated, but the damage and loss it caused were not built into the initial models. The losses to EQC were also increased because it covered the loss of land under and around dwellings. Furthermore because of liquefaction and tectonic changes in the altitude of some residential areas, some land became worthless as building sites.[28]

EQC was warned by Craig Ansley about the limitations of modelling. Amongst other issues, he warned that:

- The statistical models for earthquake hazard were based on a very short data record…, and
- Damage ratio estimates were based on one set of data from one event which may not be representative of the likely level of damage for other locations….[29]

The event from which the damage ratios were derived was the Edgecumbe earthquake of 1987. Despite the village of Edgecumbe and surrounding farms being mostly built on structurally weak alluvial soils, liquefaction was limited in extent and area.[30] Thus, liquefaction after the Edgecumbe event did not cause significant damage. Hence the damage ratios based on that event were essentially derived from shaking-damage rather than liquefaction or any other hazards.

The major conclusion for modelling from the Canterbury earthquakes is that Black Swan events will still occur. Events beyond the time horizon of the model can and do occur. That means that insurers need an element of conservatism in the application of model results. Also, secondary hazards need to be incorporated into the modelled risks.

27 BRANZ Bulletin 551.

28 For map see Te Ara Encyclopaedia of New Zealand; https://teara.govt.nz/en/zoomify/46379/eastern-suburbs-red-zone

29 Ansley (1993), pp 2-3.

30 I personally observed that limited liquefaction occurred after the Edgecumbe earthquake; also see Bastin (2017).

CONCLUSION: WHAT EQC LEARNT IN DEVELOPING DFA MODELS

Financial modelling has greatly developed in the decades since the pioneering EQC modelling described in this paper. Sophisticated models are now routine in the insurance industry.

However, the EQC experience is still relevant to innovation as well as the application of modelling:

1. **Insurers need to ask the "idiot questions."** Some leading figures in the insurance industry were disparaging and suggested that the EQC modelling was a waste of time and money. Without EQC asking questions, we may never have developed the models.
2. **Use the best people and firms that one can afford to buy**. It was quite fortuitous that Frank Russell in New Zealand and INSTRAT in Seattle had the vision and technical capacity to develop DFA models. But it was not fortuitous that EQC was using these firms, because they were world leaders in their everyday business.
3. **Be conservative in the application of modelled results**. The practice of major reinsurers (and insurers) of using multiple catastrophe models adds certainty. But models are limited in accuracy by the accuracy of the science supporting them.

AUTHOR BIOGRAPHY

In a varied career, author Ian McLean has worked as an agricultural-economist, led a United Nations Development Programme/Food and Agriculture Organization project in Tanzania, and was a member of the New Zealand Task Force on Economic and Social Planning. In his 12 years as a New Zealand Member of Parliament, he was Chair of the Parliamentary Expenditure Committee for one term. He was Chair of the New Zealand Earthquake Commission (EQC) from 1991 to 1995. He assisted in establishing the government catastrophe insurance schemes in Turkey and Romania under World Bank projects. He led the Review of the Civil Defence Emergency Management Response to the 22 February Christchurch Earthquake. McLean led the LakesWater Quality Society, which successfully stimulated the restoration program for the Rotorua Lakes. His publications include: *The Future for NZ Agriculture: Economic Strategies for the 1980s* and "Community Action and Science Help Restore New Zealand Lakes" in *Solutions Journal.* He has a BA from the University of New Zealand (Auckland) and is a Companion of the Queen's Service Order (QSO).

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