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Dynamic Risk Modelling

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Abstract

The paper describes a Dynamic Risk Model (DRM) that has been developed for the Accident Compensation Corporation (ACC) of New Zealand. The DRM consists of four scenario generators for assets, liabilities, expenses and underwriting. Each of the scenario generators has a set of base assumptions, incorporating recent trends, and a probability distribution of outcomes around these assumptions, which can allow for a wide variety of systemic risks and management actions. Many simulations are drawn from each probability distribution and the pro forma financial statements are calculated for each simulation. From these, the probability distribution for each of the output measures can be summarised and shown in various formats.

The common outputs are:

- Funding and solvency ratios;
- Capital requirements;
- Prices (or, in the case of ACC, levy rates including reserving adjustments);
- Risk measures such as Value at Risk (VaR) and Tail Value at Risk (TVaR).

The paper shows some applications that arise from linking the DRM to the scheme valuation, such as stochastic monitoring of liabilities, development of KPI’s and an improvement over the concept of actuarial release.

Keywords: deterministic, variability, stochastic, probability distribution, account

1. Introduction

1.1 The ACC has, like most accident compensation schemes, traditionally estimated its liabilities using deterministic valuation models. It has from time to time undertaken asset/liability modeling, where the variability in liability and asset projections has been modeled. The DRM was developed to:

- Bring the concept of variability into the liability valuation;
- Provide improved modeling of liabilities;
- Link the assumptions regarding variability of assets and liabilities;
- Provide a rigorous framework for monitoring; and
- Provide measures of significance to all management decisions.

1.2 This paper sets out a non-technical description of how the DRM works and some examples of the applications that have so far been identified.

1.3 The paper is structured as follows:

Section 1 - Introduction
Section 2 - A general description of DRM
Section 3 - A general description of the liability statistical models
Section 4 - The methodology used to project cash flows
Section 5 - Applications
Section 6 - Further developments

1.4 Dr Richard Brookes has been the developer and designer of much of the DRM. Dr Gráinne McGuire has been another of the major developers. Our thanks are due to them for for pushing development of this insightful and useful tool. Other collaborators have been Swee Chang, Bee Wong and Jinning Zhao of ACC. Our thanks are due to them also for assisting in the implementation. However, all the deficiencies in the description of the DRM are those of the authors alone.

2. Description of DRM

2.1 The DRM consists of interlinked modules:

- **Underwriting Scenario Generator** – produces levy income and numbers of future claims by broad type;
- **Asset Scenario Generator** – produces investment income and the asset allocation;
- **Liability Scenario Generator** – produces the benefit payments and outstanding claims provisions, based on the current portfolio and the claims generated by the underwriting portfolio;
- **Expense Scenario Generator** – produces the expenses in the income statement and the claims management expense provision in the balance sheet;
- **Projected financial statements and other output** – produces projected pro forma profit and loss statements and balance sheets from which various measures of the financial position of the organisation are derived.

2.2 This structure is shown in the following diagram:

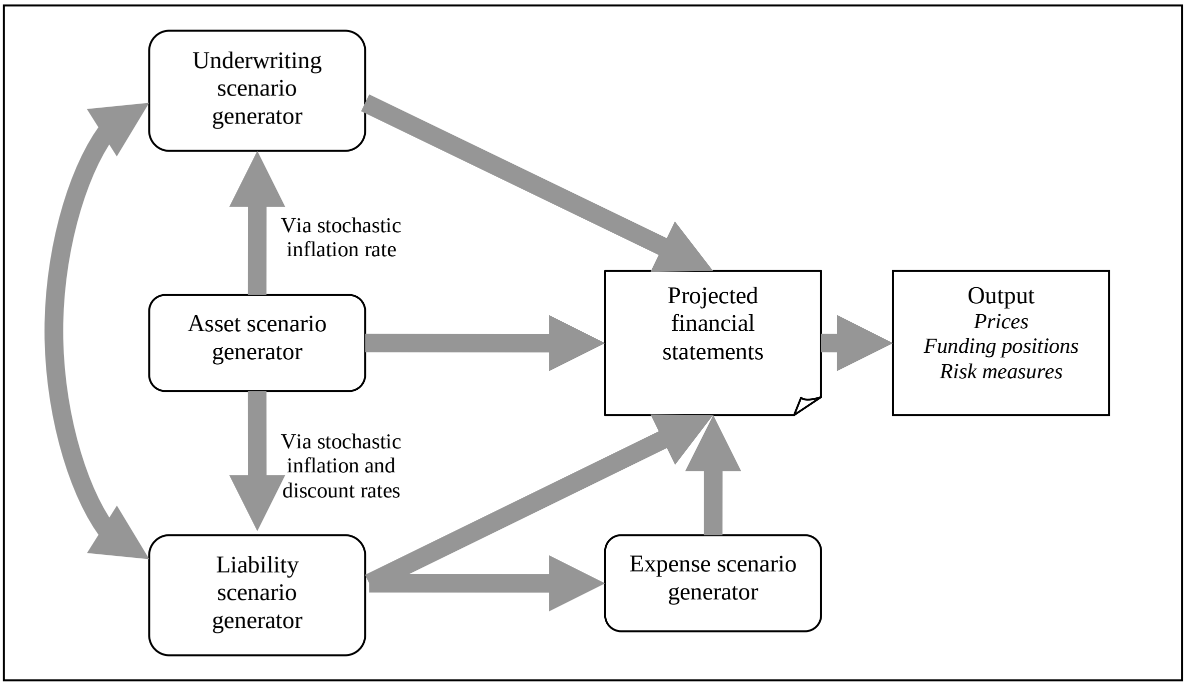

Fig 2.1 DRM schematic representation

2.3 The Underwriting Scenario Generator projects future levy income and claim numbers. It includes projections of exposure measures, such as population, motor vehicle numbers and employment numbers.

2.4 The Asset Scenario Generator is based on ACC's projected asset allocation, together with variability based on historical variability in asset returns. The projected asset allocation depends on the scheme's projected funding position and on the estimated uncertainty associated with the liabilities in the balance sheet – particularly the estimated outstanding claim liabilities.

2.5 The Liability Scenario Generator contains Insurance Modules which consider claims and payments in broad groupings. These groupings correspond to different payment types – weekly compensation, treatment costs, rehabilitation and so on.

2.6 The Expense Scenario Generator projects ACC expenses, which are in turn based on projected population numbers and claim numbers, as well as other measures of projected scheme administration requirements.

3. The liability models underlying the DRM

3.1 To date, models of liability payments have been developed for five payment types:

- Serious Injury – referred to as SI
- Weekly non-fatal – referred to as wkly
- Elective Surgery – referred to as hosp
- Other medical – referred to as omed
- Short term medical – referred to as smed

For the purposes of this paper, we have focused on descriptions of the last four payment types.

3.2 The cash flows for the four payment types are modelled with Payments Per Active Claim (PPAC) models. Each payment type model is broken down in to separate sub-models, each of which is calibrated by a Generalised Linear Model (GLM). The model and sub-model structure for each payment type is given in Table 2 1.

Table 3.1 Models and sub-models

Payment type	Sub-Models
Weekly non-fatal	• Number of activations • Number of continuing claims • Average duration paid per claim per quarter (days) • Average payment per day
Elective surgery	• Number of active claims • Average payment per claim per quarter
Short term medical	• Number of active claims • Average payment per claim per quarter
Other medical	• Number of activations • Number of continuing claims • Average payment per active claim per quarter

3.3 A claim is considered active in a payment quarter if it has received at least one payment in that particular payment quarter. Active claims are split into activations and continuing claims. Continuing claims are those claims which have received a payment of that payment type in an earlier payment quarter. Activations are those claims which have not previously received a payment of that payment type.

3.4 Each sub-model GLM is made up of:

- A set of categorical predictors derived from accident quarter, development quarter or payment quarter and interactions of these;
- A set of parameters, one for each predictor which are used as multipliers to get a linear combination of predictors for each accident, development and payment quarter. The calculation of the linear combination of predictors, using the parameters for a data point is known as the linear predictor for that data point;
- A link function (which is log in all cases so that all the models are multiplicative);
- An offset which is a term in the linear predictor, additional to that defined by the predictors and parameters, and defined in advance for each data point;
- An error distribution, which defines the statistical distribution from which the modelled variable is assumed to be drawn; and
- A weight function which adjusts the variance of the error distribution.

3.5 In general terms, the set of predictors for each model consists of the following:

- A set of predictors describing a development curve i.e. the change of the linear predictor as the development quarter changes, for a base payment quarter;
- A set of predictors describing how different sections of the development curve change as payment quarter changes. We refer to these as the development/payment interactions;
- A set of predictors which the seasonality effects i.e. how the linear predictor changes according to whether the payment quarter is the first, second, third or fourth quarter in the calendar year; and
- Various ad hoc parameters to describe special features of the dataset.

3.6 The following graphs illustrate the output from the development quarter and payment quarter models.

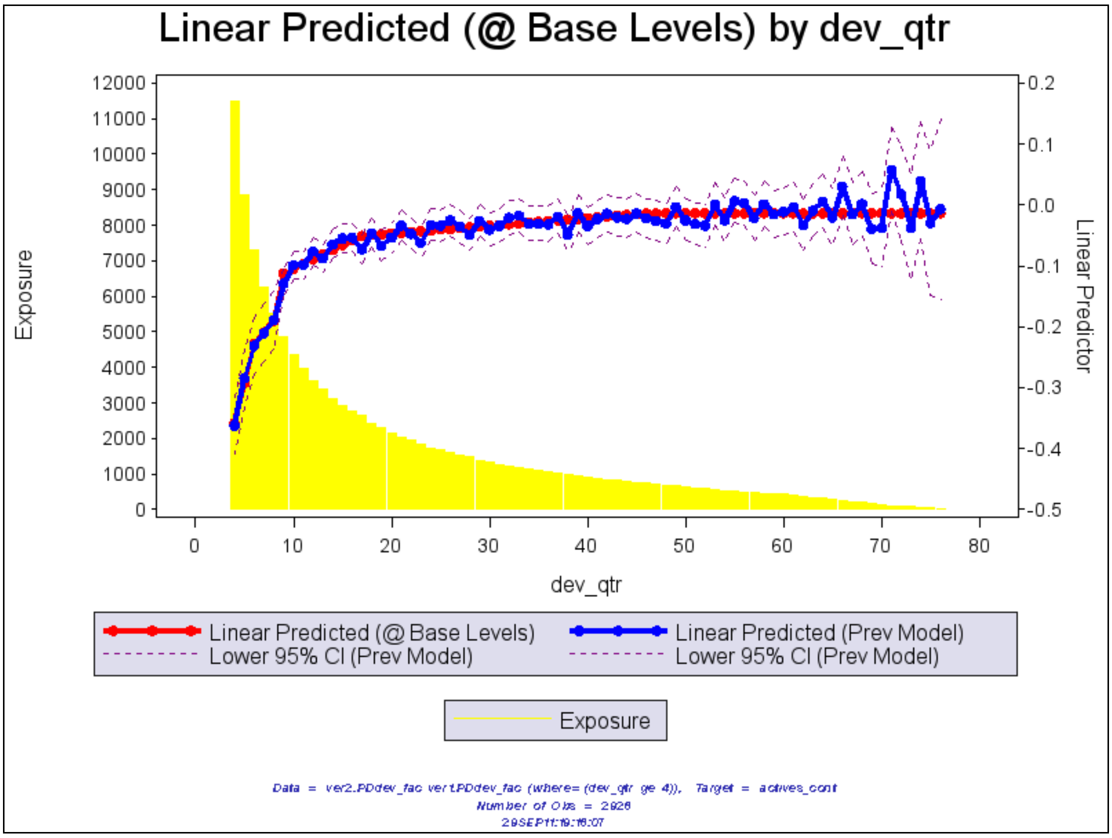

Fig 3.1 Development quarter effect – weekly continuance

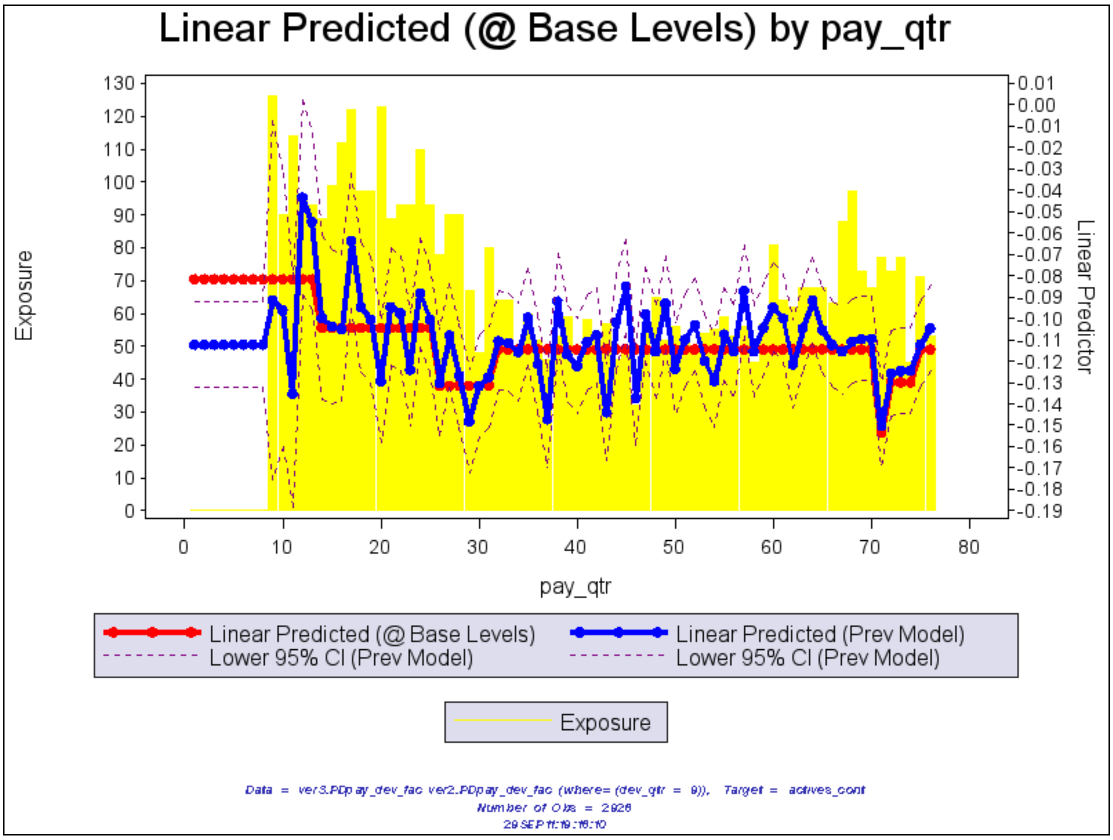

Fig 3.2 Payment quarter effect – weekly continuance

3.7 Many of the models have a seasonality component, which is introduced via predictors named qtr_1, qtr_2 and so on. qtr_1 is an indicator variable which is one when the payment quarter corresponds with the first quarter in a calendar year.

3.8 As mentioned above, all GLM models in this part of the DRM use the log link function. This means that the models are multiplicative in structure so that the effects of each predictor are multiplied together to get the final model prediction.

4. The methodology used to project cash flows

4.1 It easiest to describe the Liability Scenario Generator in two parts:

- A deterministic projection; and
- Incorporation of variability using simulations, each one of which is based on a deterministic projection.

Deterministic Projections

4.2 As discussed above, the GLM models are of the structure:

- Development curve for a base (past) payment quarter; plus
- Development/payment quarter interactions which change the level of different sections of the development curve as payment quarter varies; plus
- Seasonality adjustments.

4.3 To project claims experience into the future, it is sufficient to project the development/payment quarter interactions. If levels for these can be set for each future payment quarter then this will be enough to define the expected future claims experience.

4.4 The deterministic projection simply involves taking the existing GLM model parameters, the projections for the development/payment interactions and a small number of subsidiary assumptions, and combining them to give a projection of claim numbers and payments for each accident quarter, development quarter and payment type.

Variability

4.5 The Liability Scenario Generator outputs cash flows which incorporate the variability which can be expected in these cash flows over the future. It does this by outputting simulated cash flows. For each simulation, a complete set of cash flows is output i.e. a cash amount for each future payment quarter for each accident quarter and payment type. Each simulation represents one possible "future" and the collection of simulations can be used to calculate the statistical distributions for any given measure which is based on the cash flows.

4.6 The variability of the cash flows can be considered as coming from three different sources:

- **Process variation**. This is where the statistical models underlying the projection are exactly correct but, since claims experience is a statistical process, there will be variation in the actual outcomes. This is not under the control of management;
- **Parameter variation.** The statistical models underlying the projection are dependent on various parameters which have been measured from past data. Since there is a limited volume of past data, the estimation of these parameters is subject to error. The error in estimating the parameters will translate into experience being different than expected and so variability in the cash flows. Again, this is variation is not under the control of management although it can be minimised by the adoption of appropriate valuation models.
- **Systemic variation**. This is the variation resulting from the future environment being different from that expected in the projections. This might occur due to, say
    - Legislative change

- Change in claims management
- Changes in claiming behaviour
- Changes in claims costs e.g. elective surgery or GP rates.

4.7 The Liability Scenario Generator estimates the variation due to the first two sources using a parametric bootstrap and variation from the third source by simulating possible future changes in the environment calibrated by looking at past changes.

4.8 An illustration of the resulting projections for one payment type is shown in Figure 4.1.

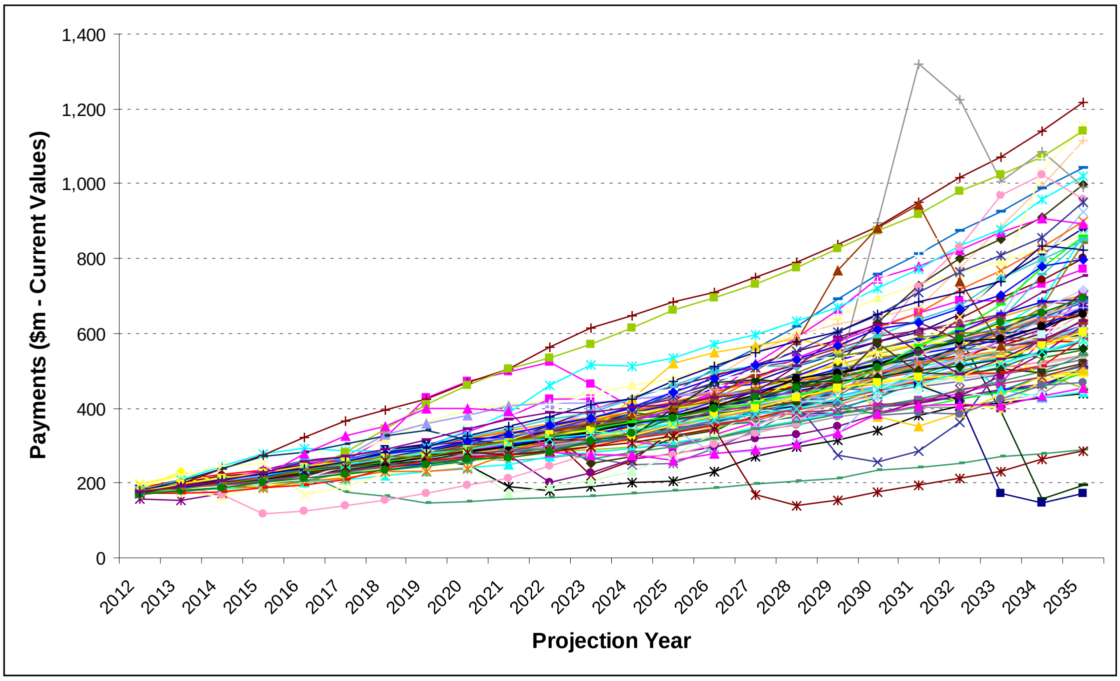

Fig 4.1 Payment quarter effect – weekly continuance

4.9 Figure 4.1 shows the projected payments from 100 simulations, with some material outliers. Depending on available resources, at least 500 simulations are usually run. From the simulations, statistical distributions based on the cash flows can be calculated. In particular, confidence bands can be placed around projected future payments.

5. Applications

5.1 The applications of DRM to date have been:

- **Investigating causes of variability**. During the model fitting, several interesting sources of variability were identified:
    - o Effects of retirement
    - o Evidence of trends
    - o Uncertainty in elective surgey numbers
- **Direct modelling of "what-ifs**". Items such as a "payment overload" can be incorporated into the model. Payment overload refers to a situation where numbers of claims are forecast to increase to a stage where they overload the available staff and cause reduced numbers of claim closures because staff are not able to manage claims as effectively as previously.
- **Review of kpis.** The model provides insight into the random fluctuations of such variables as active claim numbers. These should be considered in the setting of kpis and the monitoring of them.
- **Stochastic monitoring.** This is a tool to measure actual experience against expectations, to project surplus (similar to actuarial release) and to drill down to the driving factors.

Causes of Variability

5.2 The fitting of models to past numbers, continuance and payments and the resulting measurement of variability highlighted areas where there was an identifiable source of variability. The first example is the effect of retirements on projected weekly compensation. Figure 5.1 illustrates the comparison of the results of the current determinstic valuation (used for accounting purposes) and the results from the Liability Scenario Generator:

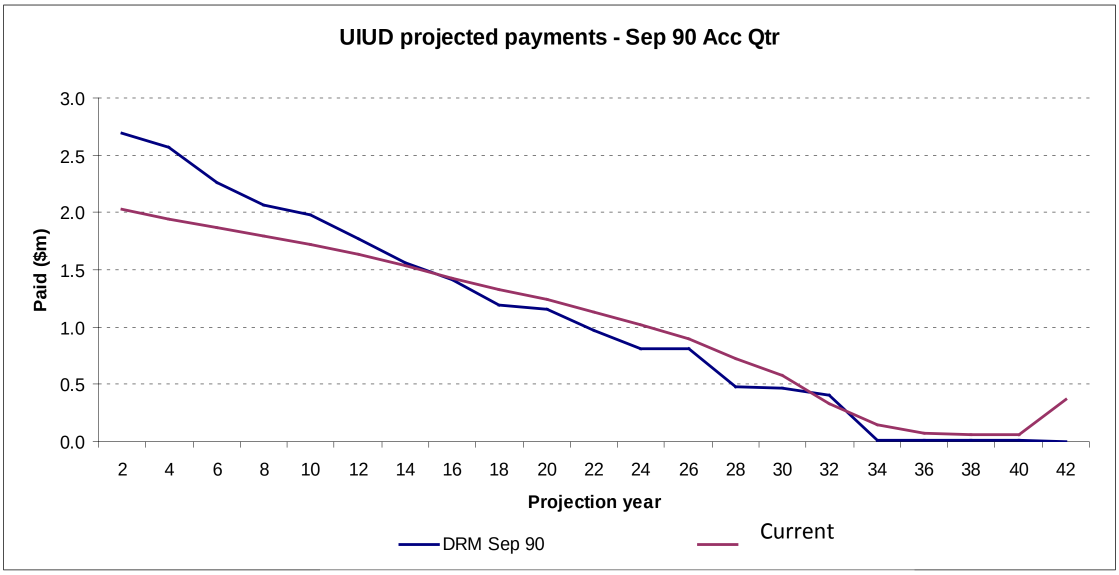

Fig 5.1 Projected weekly compensation from one accident quarter

5.3 The current deterministic model was based on continuance rates fitted to historical data, which included retirements. The Liability Scenario Generator showed much less variability when retirements were excluded from the analysis, and added subsequently. This highlighted that retirements could be expected for a maximum of 34 years from the current valuation date, and the use of average continuance rates was adding a tail of weekly compensation payments that was not pssible based on the age profile of the current claimants.

5.4 The second example is elective surgery numbers. It was clear that some claimants were having elective surgery many (20+) years after injury. The causes may be related to deterioration of the initial injury, but may alsoi be due to the combined effects of the injury and ageing. The Liability Scenario Generator highlighted that the veriability in numbers of claims was contributing considerably to the uncertainty in the liability. Figure 5.2 shows the source of this uncertainty:

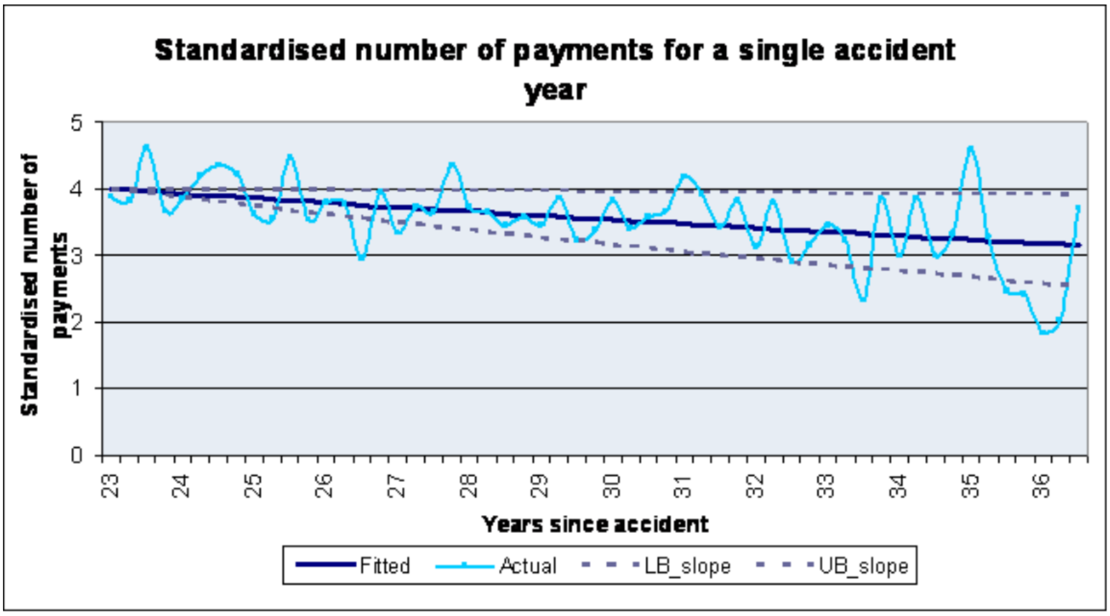

Fig 5.2 Projected elective surgery numbers

5.5 The difference between the upper and lower lines represents a 20% difference in the liability – a major source of uncertainty in elective surgery liabilities comes from a small number of claims many years after accident.

What-ifs

5.6 The models allow investigation of effects such as a "payment overload". This is where an increase in claim numbers causes a heavier work burden which in turn leads to higher continuance rates.

5.7 Figure 5.3 shows the distribution of liability estimates with and without a payment overload effect:

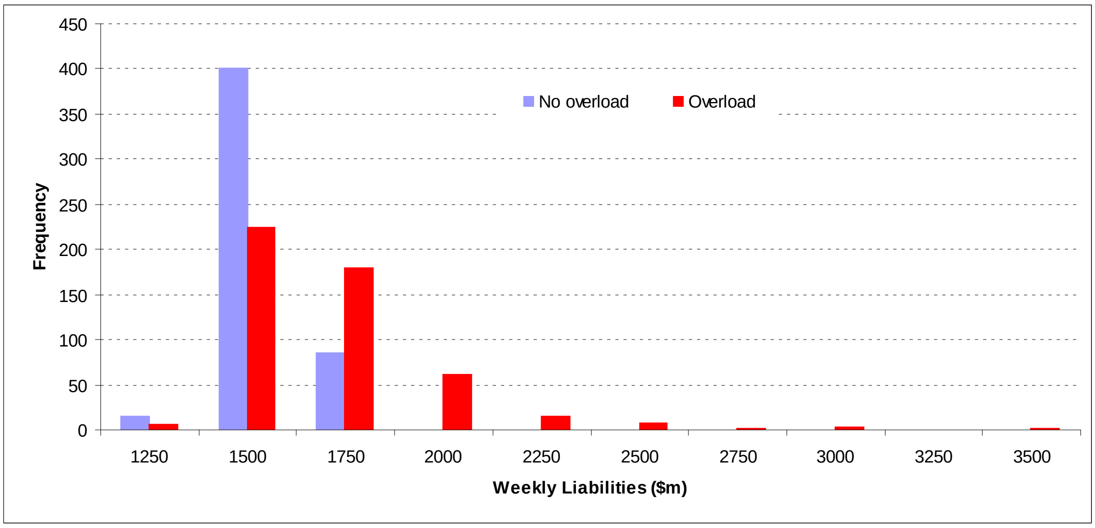

Fig 5.3 Payment overload effect

Review of kpis

5.8 The DRM provides measures of the random fluctuations of such variables as active claim numbers. This is a statistic that is actively monitored by most schemes as one of a number of kpis. In most case, these are measured at discrete points, such as the number of active claims at 70 days weekly compensation, measured at particular points of time. The models used in the DRM provide indicators of whether differences between the kpi target and the actual experience are significant, or could be due to random fluctuations.

Stochastic Monitoring

5.9 The usual basis for monitoring experience is to compare actual measures of things like claims numbers, active claims and payments with the values projected from the latest scheme valuation. These comparisons reveal differences, but not the source or significance of those differences. The Liability Scenario Generator provides measures of the variability to be expected in projections. It is a straightforward step to compare the actual outcoms with those projected, with the added measure of the variability providing an indication of whether the differences are significant.

5.10 Without going into too much technical detail, stochastic monitoring provides a comparison of the actual experience of each of the items modelled with that expected from the previous valuation. The significance of comparing the items modelled (rather than overall numbers or continunace rates or payments, say) is that it enables the user to see immediately where experience is diverging from previous models. Each of these items is one dimension of a multi-dimensional model. Changes in a multi-dimensional model are beyond the capacity of any individual to observe.

5.11 An example is provided by Figure 5.4.

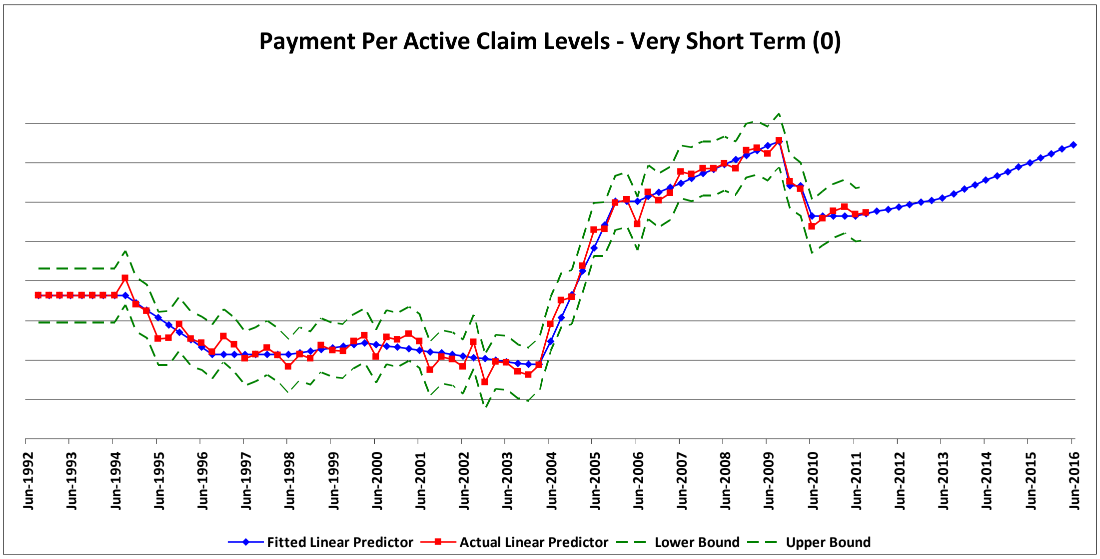

Fig 5.4 Actual versus expected PPAC – very short term

5.12 Figure 5.4 shows the model predictor of Payments Per Active Claim for development quarter 0 (labelled very short term) as a blue line. The figure shows that the recent actual PPACs have been close to the predicted values, so that no change to the model is necessary. Figure 5.5 shows a situation where the actual values have differed from predictions.

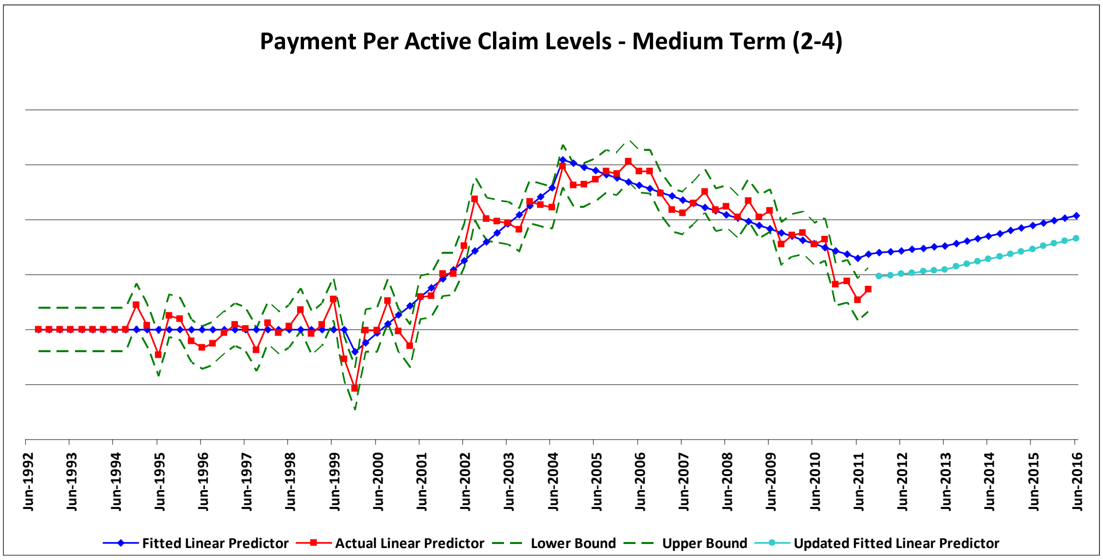

Fig 5.5 Actual versus expected PPAC – medium term

5.13 Figure 5.5 shows the model predictor of Payments Per Active Claim for development quarters 2-4 (labelled medium term), again as a blue line. The figure shows that the recent actual PPACs have been much lower than the predicted values, so that a change to the model is warranted. The aqua line shows the modified projections, which are close to halfway between the previous projection and the actual PPAC. The effect of changing the projection can be readily estimated from this revised projection.

5.14 This process is repeated for numbers and continuance rates (where appropriate). Each model predictor is compared with the actual values, and the effects of each significant deviation from expectations can be estimated, both in terms of future payments and previous estimates or projections of liabilities.

5.15 An example of the way this can be used is shown in Figure 5.6.

Fig 5.6 Stochastic Monitoring Output

Account: Example **Payment Type:** Example

Monitoring Period: 01/07/2011 **To** 30/09/2011

Opening Estimate		Change in Liabilities Due to Impact of Changes in:						Hindsight Estimate	
Date:	01/07/2011	Experience		Parameters (Indicative)		Experience and Parameters		Date:	30/09/2011
	$000s	$000s	%	$000s	%	$000s	%		$000s
Outstanding Claims	352,516	-202	-0.1%	0	0.0%	-202	-0.1%	Outstanding Claims	352,315
2012 Accident Year	32,555	28	0.1%	0	0.0%	28	0.1%	2012 Accident Year	32,583

Parameter Analysis

	Very Short Term (0)	Short Term (1)	Medium Term (2 - 3)	Medium Term (4 - 8)	Long Term (9 - 19)	Long Term (20+)
New Claims	Graphs	Graphs	Graphs	▲ Graphs	Graphs	Graphs

	Long Term (0+)
Payments Per Active Claim Levels	Graphs

✔ Likely increase in surplus from parameter change
✘ Likely decrease in surplus from parameter change
▲ Possible Increase in Surplus
▼ Possible Decrease in Surplus

5.16 Figure 5.6 shows a monitoring "dashboard" as at 30 September 2011 – it shows an opening liability estimate as at June 2011 together with an estimate of the 2012 claims cost. It also shows the effect on each of the experience, together with indicators of which predictors have caused the difference between actual and expected. The next figure shows how this can be used to project movements in claims cost (a concept similar to actuarial release) at year end progressively through the year.

Account:	Example	Payment Type:	Example

Monitoring Period: 01/07/2011 To 30/09/2011

Opening Estimate	
Date:	1/07/2011
	$000s
Outstanding Claims	352,516
2012 Accident Year	32,555

Estimated Payments	
From 1/07/2011 to 30/06/2012	
	$000s
Outstanding Claims	15,763
2012 Accident Year	1,840
Total	17,603

Closing Estimate	
Date:	30/06/2012
	$000s
Outstanding Claims	336,753
2012 Accident Year	30,715
Total	367,468

Adjusted Estimated Payments	
From 1/07/2011 to 30/06/2012	
	$000s
Outstanding Claims	15,562
2012 Accident Year	1,868
Total	17,430

Adjusted Closing Estimate	
Date:	30/06/2012
	$000s
Outstanding Claims	336,753
2012 Accident Year	30,715
Total	367,468

Fig 5.7 Projection of actuarial release

5.17 Figure 5.7 shows the same opening position, but breaks the change in liabilities down into its components – the adjusted projected payments for the year versus the previously expected payments and the adjusted projected liability versus the previously projected liability at year end. The adjusted payments includes actual payments for the September quarter plus any adjustments made as a result of experience in that quarter (as illustrated in Figure 5.5). The adjusted projected liability includes any adjustments made as a result of experience in the September quarter.

5.18 The benefits of the stochastic monitoring tool are that:

- it shows what factors have differed from previous modles
- it shows whether the differences are significant
- it projects the effect of significant changes on payments and liabilities. In effect, it provides a moving forecast of the movement in claims cost for the year as experience emerges, from which the emerging actuarial release can be derived.

6. Further developments

6.1 The further developments of the DRM include:

- **Refinement of the actuarial release concept.** The stochastic monitoring tool provides both measures of the main drivers of experience (numbers, continuance or payment size) and projections of the actuarial release if the current levels of each are maintained. These projections will become closer to the end of year actuarial release, as each quarter's experience emerges.
- **Input into kpis.** The stochastic monitoring tool provides a comparison of the experience of each predictor with the previous model. As discussed above, it provides an objective measure of each dimension of a multi-dimensional model. It is therefore able to pick up changes more accurately and more quickly than actuaries using spreadsheets and judgement. This should provide insight into the usefulness of current kpis.
- **Scenario projection.** Scenarios involving changes due to tightly focused groups of claim, particular payment types that are not treated separately in the valuation, can be incorporated into the DRM. The methodology would be as follows:
    1. The DRM would access a unit record claim file which records various items about each claim;
    2. For a particular change which targets a group of claims and payments, the DRM would calculate the proportion of claims and payments of each relevant valuation grouping which is made up by the target group over the last year;
    3. The effect of the change on the target group would be expressed in terms of the simplified valuation model parameters;
    4. The DRM would take the proportions from Step 2 and the effects from Step 3 and combine them to give an effect for each future year on the cash flows and provisions.
    5. This will capture the ability to do quite detailed scenario testing without becoming unnecessarily complex.

6.2 The model