MODEL GOVERNANCE AND RATIONAL ADAPTABILITY IN ENTERPRISE RISK MANAGEMENT

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M B Beck, D Ingram, and M Thompson

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Tel: +1-613-236-0886 Fax: +1-613-236-1386
Email: secretariat@actuaries.org
1203-99 Metcalfe, Ottawa ON K1P 6L7 Canada
www.actuaries.org

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M B Beck
London, UK
Guest Scholar, International Institute for Applied Systems Analysis, Laxenburg, Austria

D Ingram
Executive Vice President, Willis Towers Watson, New York, USA

M Thompson
Bath, UK
Guest Scholar, International Institute for Applied Systems Analysis, Laxenburg, Austria

SUMMARY

The problem context of this work is what has been called the “Insurance Cycle”. In this cycle we recognise four qualitatively different risk environments, or seasons of risk. We address the use of models for supporting an insurer’s decision making for enterprise risk management (ERM) across all four seasons of the cycle. In particular, the report focusses expressly on: first, the matter of governance for dealing with model risk; and, second, model support for Rational Adaptability (RA) at the transitions among the seasons of risk. This latter examines what may happen around the turning points in the Insurance Cycle (any cycle, for that matter), when the risk of a model generating flawed foresight will generally be at its highest.

Work on governance for model risk, our first topic, is shaped by our prior participation in the IFoA Working Party on Model Risk (2013-2017) and a 2016 Bank for International Settlements (BIS) Seminar on “Solvency and Global Capital Standards for Insurers”. Research on our second topic, model support for RA, has been inspired (in part) by a pioneering cross-disciplinary collaboration of the 1970s — in applying control theory to problem-solving in actuarial science — which is reviewed in detail. The resulting insights are then developed into the framework for RA, as originally expressed in a Compendium of six articles published in InsuranceERM between 2009 and 2013.

The nature of the present enquiry is one in which the application of cross-disciplinary Systems Thinking is defining. Overall, three core disciplines are deployed (in depth) in the research: actuarial science and practice, which self-evidently is central; social anthropology, upon which is built the framework for governance in addressing an insurer’s need to cope with model risk; and control theory, from which basis is developed the companion framework for employing models in supporting RA. And RA itself, we note, has always been cast as a matter of the social anthropology of the risk culture of actuarial practice. Its theoretical basis is the theory of Plural Rationality (Cultural Theory), which defines and distinguishes the form of governance proposed by the IFoA Working Party for coping with model risk.

Significantly, in respect of cross-disciplinary Systems Thinking, the adaptive nature of decision making for RA has much in common with modern control theory, in particular (unsurprisingly), what that discipline calls adaptive control. More surprising, perhaps, is the
fact that the theory of Plural Rationality in social anthropology should draw upon catastrophe theory (as it does) as the conceptual basis for understanding stability, instability, and resilience in the dynamics of a system, be this the market place, an enterprise’s financial performance, the social-power dynamics of decision-influencers within that enterprise, or whatever. Indeed, as empirically observed, such power dynamics lie at the heart of what we have said earlier of “A Strategy to Suit Each Point in the Insurance Cycle”, in the closing article of the InsuranceERM Compendium. Still more surprising, is the manner in which anthropology and catastrophe-cum-control theory may be knitted together in order to explain a Keynesian economic account of trade cycles (a quite unusual case history of which must be retold in order to reach from control theory to model support for RA). Economics, therefore, is also brought into the mix of cross-disciplinary Systems Thinking, albeit in a minor way.

Going the other way across the cross-disciplinary bridge of Systems Thinking — from RA and anthropology back to control theory — we find an already existing companion framework to RA. It is called Adaptive Community Learning. Anthropological-sounding enough, the procedure is yet rooted in control-theoretic approaches to diagnosing and exploring the potential for imminent structural change in the behaviour of a system (the environment, the climate, the economy, and so on). And that, we argue, is closely akin to the way in which model support for RA should deal with qualitative shifts in a company’s risk environment (turning points in the Insurance Cycle) and nurture the skills needed for attaining resilient company behaviour over the longer term, from one turn of the Cycle to the next.

Our recommendations from this project run likewise the gamut. The first (of ten) recommendations proposes that the cross-disciplinary Systems Thinking of this report should be incorporated into the canon of continuing professional development materials for actuarial practice — a principal agenda item, notably, of the soon-to-be-launched Financial Systems Thinking Innovation Centre (FinSTIC) of the IFoA. The last recommendation calls for the development of an additional, quite distinctive rationality for exercising and implementing RA itself, with arguably its own equally distinctive kinds of supporting models (and, lest we forget, what would be their associated risks).

In between these immediate-term and long-term targets, our recommendations outline variously the following:

How our proposed novelty of (computational) cultural sensitivity testing might be implemented in standard commercially available software packages for actuarial risk models.

How cultural diversity (a diversity of risk-coping rationalities) might be used to advance a contemporary and prototypical study of “reverse sensitivity-stress testing” of the types of models currently in use by firms participating in the London insurance market.

How, in particular, both of the foregoing should be deployed for “pre-emptive investigatory examination and challenge”: the deliberate touching of a plurality of bases prior to making a decision, not just the one base of some imposed or collectively self-willed group think. In this the bases to be touched are deliberately pushed as far apart as possible according to the theory of Plural Rationality.

This last, we note, is very much our response to the emerging concerns regarding systemic, industry-wide risk arising both from a lack of commercial model diversity and from
(unintended) regulatory “corralling” of potential decision strategies into practices tantamount to group think — something already apparent at the 2016 BIS Seminar.

**Guidance**

This is an unexpectedly lengthy project report (unexpected for its authors, that is), hence some guidance.

For those readers daunted by the report’s length, we note that its main results, with regard to governance for model risk and model support for Rational Adaptation (RA), are to be found in Sections 3 and 4 respectively, in particular Sections 3.4 and 4.5.

For those who wish to begin by examining the implications of our work, before immersing themselves in the detailed reasoning underpinning them, we suggest a read through our Recommendations in Section 5. Section 5 is itself quite extensive, with most key points anchored back to the body of the report, i.e., Sections 3 and 4.

Last, if there is a kernel to cross-disciplinary Systems Thinking, then it is to be found in Section 4.3. It may not make for easy reading, we fear — despite what is therefore the preparatory preamble to it across all the preceding Sections of the report.
1 INTRODUCTION

Using a flawed model can be costly. Losses and fines may run into the hundreds of millions, even billions, of dollars (Aggarwal et al., 2016; pp 230-1). It is no surprise, then, that over the past decade concern for such “model risk” has risen to prominence: that it should be treated as a separate line item of enterprise risk management (ERM) in its own right; and that there should be protocols and procedures for guarding against it (Federal Reserve, 2011; HM Treasury, 2013). In 2013, therefore, the (UK) Institute and Faculty of Actuaries (IFoA) established a Model Risk Working Party (WP) to address and study the issue. Its report, from what turned out to be Phase I (2013-15) of the WP’s deliberations, sets out a comprehensive, if prototypical, framework for coping with model risk (Aggarwal et al., 2016). At the heart of that framework can be found the matter of “model risk governance” (Aggarwal et al., 2016; Figure 1; p 240), which in turn is duly unfolded — again in prototypical form — as a matter of “model culture” (Aggarwal et al., 2016; pp 256-267). And that model culture is defining for this present work. It has its roots in the book Cultural Theory (Thompson et al., 1990). Significantly, it can be referred to alternatively as a theory of plural rationality, the essence of which has been caricatured as the “split personalities” diagram of Figure 1, which appeared as the front cover of the December, 2014, issue of The Actuary. The attaching article (Tsanakas et al., 2014) pre-figured what was to be recounted more fully and formally as the topic of governance and model culture in the final report of Phase I of the IFoA Model Risk WP (Aggarwal et al., 2016).¹

Looking back, it surprises us how soon was Figure 1 published (2014) after the original introduction of the theory of plural rationality into actuarial practice. For the conjunction of the two has but barely a ten-year history, time-stamped, as it were, by a 2009 article in Contingencies enunciating “The Law of Risk and Light” (Ingram, 2009a) and a series of four articles diagnosing the empirical evidence of plural risk-coping behaviours during the 2008-9 credit crisis. Which articles appeared in the January, March, May, and July, 2010, issues of Wilmott Magazine as Ingram (2010), Ingram and Thompson (2010a), Ingram et al (2010), and Ingram and Thompson (2010b)). These latter discuss how people with plural rationalities can, in their power plays, induce the violent gyrations we often observe in the market place. Crucially, the conjunction to which we are referring was driven not by an anthropological theory chasing after some tame, convenient problem, but by actuarial practice: specifically, the development of an insurance ratings protocol for Standard and Poor’s (S&P). The plural rationalities — the plural, distinctively different ways of conceiving of and coping with risk — existed “naturally” “out there” in the everyday practices of some 125 insurance companies around the globe. They did not have to be concocted according to any theoretical recipe. They were part of the world as observed, admittedly from an especially privileged observing position (that of a ratings agency).

¹ Phase II of the WP’s deliberations focussed its attention on matters of model risk other than that of governance (Black et al., 2017).
In this report, we build on the outcome of Phase I of the IFoA’s Model Risk WP (Aggarwal et al., 2016), first, to extend application of the theory of plural rationality to framing a desirable form of governance for model risk and, second, to progress towards how the model itself might be used deliberately to counter model risk, again according to the theory of plural rationality (Section 3). These further developments are gathered around fairly extensive reviews of three pieces of work on:

(i) the regulator’s perspective on model risk, as this emerged from a 2016 Seminar of the Bank for International Settlements (BIS) on “Solvency and Global Capital Standards for Insurers”;

(ii) results from an empirical study of governance for coping with model risk based on interviews with some 31 practitioners in the London insurance market (Tsanakas and Cabantous, 2018); and

(iii) results from a simulation study of the problem of industry-wide systemic risk arising from a narrowness of significant structural variety.

Figure 1. The “split personalities” of Plural Rationality (as pictured on the front cover, The Actuary, December, 2014).
in the use of models for managing risks from natural catastrophes (Heinrich et al, 2019).

None of these studies, as it happens, deals expressly or even implicitly with cyclical behaviour in the risk environment.

Whereas Section 3 is defined by a theory drawn from social anthropology, Section 4 begins with a review of an early cross-disciplinary study of oscillatory (cyclical) behaviour and instability in claims processing in an insurance firm and the use of control theory for stabilizing such behaviour (Balzer and Benjamin, 1980; Benjamin, 1982; Balzer, 1982). The goal of Section 4 is ultimately to examine how some conjectures from control theory, when interwoven with the companion anthropological hypothesis of plural rationality, can begin to extend our understanding of Rational Adaptability and its implementation in practice. In the process, we pass from the studies of Benjamin and Balzer through two more recent, more mathematically advanced control theoretic studies (Zimbidis and Haberman, 2001; Yang et al, 2016). We thus derive and shape a somewhat different appreciation of how it is that the more strategic, qualitative shifts in a company’s risk environment can be manifest in the insurance cycle: how it is, indeed, that an insurance cycle may be created (Clark, 2010). From this, Section 4 turns to trade cycles in general, to Keynes’ explanation thereof, and his fundamental psychological law accounting for the role of individual motivation in economic theory. That Keynes’ account fails to explain why it is that a “pig cycle” is induced in a ceremonial tradition of gift-giving in New Guinea, is due to what control theorists would refer to as a time-varying “constant” (or parameter) in the model of the behaviour of this unexpected and unusual system (Thompson, 1979). The purpose of this excursion into the seeming depths of social anthropology (and there to find a nascent sense of plural rationality) is to set out our reasoning about the deliberative use of models in support of RA in ERM. The telling points about the anthropological analysis of the pig cycle are that, first, it is based conceptually and visually on catastrophe theory, a very close cousin of control theory, and, second, the presence of time-varying parameters in a model is indicative of structural change in that system’s behaviour. How one conceives of the challenge of RA can therefore be likened to the problems — and solutions — resulting from our extensive prior research on generating foresight (with models) in the presence of structural change (Beck, 2002).

Our report is closed with our recommendations for the next steps to be taken in order to have the results of Sections 3 and 4 implemented in practice (in Section 5).

But before embarking on any of the above, we set out the context of our work and proceed from there to define the problem to be addressed in abstract, technical terms. This we do (in Section 2) in the interests of maximising clarity and precision in our subsequent reasoning. After all, the challenges of coping with model risk and adapting a company’s decision-making strategy in the face of qualitative cyclical shifts in the company’s risk environment are not straightforward.

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2 We owe this phrase to Gillian Tett, anthropologist and former North American Editor of the London Financial Times. She coined it in her article “Anthropologists join actuaries on risk” (Financial Times, 2 August, 2012).
1.2 Preamble and Context

The theory of plural rationality deals with the plural, mutually opposed ways of understanding the world and acting in it. Equivalently, we can say that “risk culture refers to how things are seen, done and justified” (Underwood et al., 2013). To ease our talking about such plural rationality (at this introductory stage), it will be helpful to refer to the plural ways of coping with risk as risk-seeking, risk-avoiding, risk-managing, and risk absorbing. There is, of course, nothing new about a plurality of this kind, at least not the twofold, perhaps even threefold typologies thereof. The risk-seeking and risk-avoiding stances have long been widely recognised, as too has (for some) the risk-managing stance. Yet the fourfold, or (strictly speaking) fivefold, plurality of our theory is likely to be unfamiliar to most.

At bottom, therefore, we are asking the reader to accept (for now) that a risk-absorbing actuary, say, sees the ways and workings of the world very differently from a risk-managing, risk-seeking, or risk-avoiding actuary — hence the four basic rationalities. Thus the risk-absorbing actuary acts (makes decisions) very differently from the other types of actuaries with their very different notions of the way the world is. There may be — and should be, we shall argue — four (if not four sets of) qualitatively different, usually sharply opposed, candidate decisions a firm may eventually enact. What is more, since any given individual in a firm at any given time may be a wholly committed risk-avoider with respect to the decision about to be made (or risk-seeker, risk-manager, or risk-absorber), it is not hard to imagine that the power and influence this individual enjoys (or not) within the organisation at that moment will have a bearing on whether her/his preferred candidate course of action is adopted as the decision.

But nothing prevails for ever. There will be “power dynamics” among the firm’s employees; and the consequences of the endless playing out of these dynamics within the firm will influence, and be influenced by, the firm’s success or failure in the market place. Underwood and Ingram’s (2013) expression of the insurance cycle, with its six stages through time, deploys rich empirical experience (almost in passing) to explain how one particular risk-coping style might hold sway in any given phase of the cycle, but fall from grace as that phase in the cycle changes to another. Similarly, working from the theory of plural rationality, if the decision-making rationales that follow from the four archetypal risk-coping styles are mechanized in a computer simulation of firms competing for business in a market place, that market displays the cyclical, life-like ups and downs we all know so well (Ingram et al., 2012a). And just as there are four risk-coping styles, so there are four “seasons” of risk in the market place: risk-seeking is matched with the season of market Boom; risk-avoiding with market Bust; risk-managing with market Moderate; and risk-absorbing with market Uncertain (Ingram, 2009b, 2019). Yet how the internal power dynamics might have played out in each simulated firm of the so-called Surprise Game of Ingram et al (2012a) — or might better have been deliberately harnessed and orchestrated through forms of governance — was not simulated. That would have been quite an advanced piece of simulation work indeed. Nonetheless, the waxing and waning of power and influence in an organisation are a deeply important, if rarely discussed, part of the theory of plural rationality (see the last chapter of Thompson, 2008a).

How plural candidate decisions within a firm become the eventual, singular decision enacted by that firm — through the processes of argumentative deliberation and governance and,

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3 We shall leave the little-discussed fifth rationale to emerge only at the close of this report (in Section 5), where it will be introduced as a rationality with a most interesting (and potentially pivotal) character of very special relevance to Rational Adaptability.
crucially, when a model is being employed to guide and support development of the plural sets of candidate decisions — is the focus of this paper.

The contrasting singularity of “group think”, whether imposed or collectively willed upon all concerned, is well recognised as unhealthy for a business (see, for instance, IFoA, 2016). If the occurrence of group think is tantamount to the touching of just one base prior to going ahead with a decision, our concern in this paper is with arranging for and facilitating the touching of plural bases. The lack of diversity about group think, moreover, would be quite the opposite of that level of ever higher deliberative quality enabled distinctively, if not uniquely, through the theory of plural rationality (Ney, 2009). It is towards such a higher deliberative quality in governance that the company should be striving — not least for coping all the better with model risk. And that, from a regulatory (and compliance) perspective, is surely very important indeed (Federal Reserve, 2011; HM Treasury, 2013).
2 DEFINING THE PROBLEM

Let us begin by considering the archetypal decision context in a firm.

It is decision time $t$. The previous decision time was $t-1$; and the next will be $t+1$.

The firm may be wanting to decide about one or a host of actions: setting the premium associated with its product, i.e., pricing its product; choosing a point along the looseness-tightness continuum of the standard of insurance attaching to that product; changing the firm’s reserves in the interests of remaining solvent or complying with solvency regulations; determining whether to purchase re-insurance, or whether to invest in, or liquidate, this, that, or the other asset; or again, determining whether to purchase derivatives for hedging against adverse stock market conditions; and on and on.

With respect to making the current decision at $t$, each decision-influencing individual in the firm may, as we have said, hold (perhaps passionately) to a particular rationality: risk-seeking; risk-avoiding; risk-managing; or risk-absorbing. Associated with this rationality is a particular belief about the way the world works. For example, a part of the world of gripping interest to a given individual may be a belief or heuristic for reasoning about and gauging the way customers will respond (by time $t+1$) to a product released now (at time $t$) with a particular premium. Alternatively, it may be a belief about how the firm’s reserves might evolve by $t+1$ as a function of central bank interest rates and stock market “sentiment”; or about how the firm’s competitors will be responding by $t+1$ to this firm’s product performance as a consequence of the decision at hand now (time $t$). Clearly there may be a multitude of such facets of the world out there that the individual deems have a bearing on the decision to be made right here and now.

Also integral to the rationale to which the individual cleaves is her/his aspiration for the firm’s operating performance at $t+1$, say, for instance, its status along the loss-profit continuum.

There is, however, no obligation for any model to be employed by the firm in arriving at and implementing the firm’s decision at time $t$.

2.1 Enter A Model

What is it then — quintessentially and above all else — that the use of a model brings to the decision-making table as set out in the foregoing? It is, of course, a piece of information about the future status of something at time $t+1$.

To discuss how exactly we shall be conceiving of this extra — and the model that generates it, thus the attaching model risk, hence governance for such model risk — the introduction of some systems thinking from control theory is now appropriate.

Whatever it is in the world that grips the decision-relevant interest of an individual, that piece of the world needs to be “cut out” from the web of complex interactions among all those things within which it sits (which is the world), thus to define the system, with the logical complement of the system’s “environment”, i.e., everything else. The firm is one such system; the market for its insurance products is another; each market by which a firm’s investment asset class is defined is another; the stock market another; the national economy yet another, and so forth. Significantly, and here is where control theory departs somewhat from customary actuarial
wording and practice, the system’s inputs are those entities emanating from the system’s environment and judged by the individual model analyst to impinge significantly on the behaviour of what matters in the system. These are, therefore, input system disturbances. In a (control theoretic) model of the system’s behaviour they would be labelled \( d(t) \) and be qualified as a function of time \( t \), because in general they will vary with time. Central bank interest rate changes are \( d(t) \) in terms of an asset or stock-market system. The disturbance will influence something in the system, which something will influence something else, and on and on, such that the ramifications and consequences of \( d(t) \) are propagated through the system to end up as changes over time in the magnitudes of the output responses \( y(t) \) of the system.

Technically, these outgoing \( y(t) \) impinge back on the system’s environment, as much as the \( d(t) \) emanate from it. That insurers refer to a “risk environment” is entirely apt. It is whence derive the sequence and ensemble of events that may strike the system of the company, i.e., its \( d(t) \). Typically, a system’s output response — such as the financial results of the company, or, in the larger systems context, the value of the S&P 500 stock market index or the GDP of a national economy — is something indicating the state of the system that is of gripping interest to the onlooker. And while the system might conceivably be judged for some span of time to be in stasis (at steady state, in equilibrium), with the values of its \( y(t) \) not changing with time \( t \), such behaviour is quite exceptional. In general, we understand the behaviour of the system to be dynamic in principle, always. It is never truly static or in a steady state — never!

If a model is constructed of the system’s behaviour, the structure of the assembly of mathematical relationships for what are believed by the model analyst to be the workings of the system — those mechanics that define how the \( d(t) \) are transmitted and translated through the system to become the \( y(t) \) — will be said to be “parameterized” through a set of model parameters \( \alpha \). In other words, these \( \alpha \) are what are commonly referred to as the “constants” in an equation, or as “input factors” in actuarial vocabulary, or as the statistics (mean, variance, for example) that parameterize a probability density function, including the probability density functions and correlation properties of the \( \alpha \) and the \( d(t) \), even the temporal correlation properties of the latter.

### 2.2 The Difference the Model Makes

The extras that use of a model brings to the decision-making table are therefore these:

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4 The following is a useful (comparative) definition of a model from Cabantous and Tsanakas (2019), i.e., one expressed in their “actuarial speak” as opposed to our “control speak”. It is duly annotated for present purposes. To quote, then, Cabantous and Tsanakas say: “Broadly, capital models consist of two elements: a (stochastic) vector of ‘risk factors’ [our input system disturbances \( d(t) \) and/or our soon-to-be-introduced model parameters (coefficients) labelled \( \alpha \)] and a (deterministic) ‘aggregation function’ [the cogs and wheels of the model, as we would phrase it, as represented herein by the \( \alpha \)]. Risk factors are random variables representing quantities whose future values are unknown at the time of modelling, such as the frequencies and severities of insurance claims, incidence of natural catastrophes, asset returns, inflation. The probability distribution of risk factors is specified by statistical assumptions. The aggregation function maps ["transcribes", in our phrasing] risk factors to quantities of interest [our \( y(t) \)], such as the profit and loss of the portfolio or of individual lines of business at a given time horizon. It thus reflects important features of the insurer’s portfolio of risks, such as characteristics of the policies that the insurer underwrites and the reinsurance that the insurer buys. The aggregation of risk factors is performed via Monte-Carlo simulation and implemented in specialised proprietary software, which produces a summary of the company’s risk profile and key metrics used in business decisions.”
A formal representation of the mechanics of how the system comes to be at status $y(t)$ given that previously it was at $y(t-1)$; and

(ii) A piece of foresight, namely an estimate $\hat{y}(t+1)$ of where the system will be at time $t+1$, in which notation the little $\hat{}$ appearing above the $y$ distinguishes this foresight estimate from where the system actually ends up at $t+1$.\(^5\)

## 2.3 Cycles and Seasons of Risk Over Time

If decision times can be labelled $t-1$, $t$, and $t+1$, let us use the upper-case equivalents to denote the "macro time" over which the seasons of risk are changing as $T-1$, $T$, and $T+1$. To give substance to the abstraction of this notation, consider the commonly encountered sequence of the four seasons in the market place:

(i) the season of Moderate, denoted $T-2$, which period might have spanned perhaps several past "micro-time" decision points, for example, $t-6$, $t-7$, $t-8$, $t-9$, $t-10$, $t-11$ (or whatever), receding back into the past; then

(ii) Boom over span $T-1$, which occupied micro-time decision points $t-2$, $t-3$, $t-4$, and $t-5$; followed by

(iii) Bust at $T$, which occupied one slot of the immediate past $t-1$ and currently occupies the present micro-time slot $t$; with perhaps then

(iv) an Uncertain season in macro-time $T+1$, possibly to arrive in $t+1$ and endure until micro-time point $t+4$.

Macro time $T$ marks the passage of time with respect to things that change relatively slowly or relatively infrequently, which changes might be described as low-frequency fluctuations. Micro time $t$ marks the passage of time with respect to things that change relatively quickly or relatively frequently — high-frequency changes, therefore.

With respect to matters of governance for decision-making and Rational Adaptability, in particular (in Section 4), the universe of time may be divided into two:

*Condition (A)*. This covers a period of current time when decision points \{$t-1$, $t$, and $t+1$\} can be subsumed within any single, given, current, ongoing season $T$, i.e., the season is unchanging.

*Condition (B)*. When season $T-1$ turns to season $T$ between decision points $t-1$ and $t$ or, similarly, when season $T$ turns to season $T+1$ between $t$ and $t+1$, i.e., we are experiencing transitions between seasons.

\(^5\) Strictly speaking, of course, what the model calculates to be the current statuses of the system’s outputs (at time $t$) and their past status (at $t-1$) are every bit as much estimates ($\hat{y}(t)$ and $\hat{y}(t-1)$ respectively) as any forecasts of future statuses.
The phases, seasons, or stages in the cyclical behaviour exhibited by a system, such as the insurance market or derivatives market, their sequencing, their causes and consequences, and how foresight models might be deployed to cope with these consequences, are all — to reiterate — of central importance to this report. It is their demonstrable manifestation in the insurance cycle that, in fact, presents the most challenging set of circumstances for guarding against the consequences of model risk. They, hence Condition (B), will be the focus of Section 4. Previous studies of model risk and its governance have been focussed on circumstances under Condition (A), with even micro time $t$ present only by implication, as we now see.
3 GOVERNANCE AND MODEL RISK

Insofar as the theory of plural rationality has been (and might be) applied to ERM, let us distinguish among three sets of circumstances:

(C1) Use of a model as support for decision-making is simply absent from the decision context;

(C2) A model as support for decision-making is contemplated by all and used by some; and

(C3) The model is designed and deployed in ways intended expressly to enhance the deliberative quality of governance for coping with model risk.

Although it may seem as though our previous work has employed a model (in support of decision-making), the agent-based model of the Surprise Game (Ingram et al, 2012a; Thompson and Tayler, 1985) simulates merely the decision rules a firm may use to cope with its perception of the risks to which the firm is exposed. The Surprise Game does not have a "foresight model within a model". The decisions its simulated agents make are not in any way informed by a computational model of the simulated firm’s assets and liabilities or a model of the future inclinations of the market place into which the firm is selling its products.

We shall begin then with this least complex of circumstances — the absence of a model (Circumstance (C1) above) — for reviewing the penetration hitherto of the theory of plural rationality into the actuarial practices of insurance companies. But first, more must be said of the plural rationalities that are one of the two (theoretical) pillars of our analysis herein (the other being that of control theory, in Section 4).

3.1 The Four Archetypal Rationalities

"Beyond Boom and Bust" is how the argument in favour of four (neither two nor three) seasons of risk was boldly put back in 2008 in Thompson (2008b), as the great financial crisis of 2008-9 was breaking. He was writing, we note, just before the Ingram-Thompson collaboration that led to the 2010 articles for Wilmott Magazine. And that in turn preceded publication of the first of a sequence of six articles — to which we shall refer as a Compendium on Rational Adaptability — in which the empirical evidence in support of the four seasons was advanced (InsuranceERM Compendium, 2009-13; p 3). The evidence comprises variations over some 35+ years (1976-2012) in a US house-price index; it has been used more recently in a February, 2019, AFIR-ERM webinar (Ingram, 2019).

The original (2008) argument for the four seasons of risk ran as now follows. It was driven by the theory of plural rationality. Its re-iteration here allows us to introduce the essentials of the theory in a context illustrative of the remainder of this report.

From the 1940s, with Keynes and Hayek, and on through the 1980s-90s, with Arthur Seldon (founder of the UK’s Institute of Economic Affairs), economic affairs (indeed) were believed to be those of a duopoly: of free markets, on the one hand, and government regulation, on the other. The pendulum would swing back and forth between the two, between light-touch and heavy-handed regulation. Or, put more subtly and technically, economic affairs were understood as a matter of, on the one hand, unfettered-competition-with-symmetric-
transactions ("markets", in short) and fettered-competition-with-asymmetric-transactions ("hierarchies"), on the other. And yet, as the article asks (Thompson, 2008b; p 36):

why should there be just two ways of organising if, as economists and political scientists have long argued, there are four kinds of goods: private, public, common-pool and club?

Competition, with its continuum from unfettered to fettered, and transactions, with their continuum from symmetric to asymmetric, constitute two orthogonal axes, with accordingly four quadrants for the four pairwise combinations of the "poles" of the two axes. Figure 2 can therefore be plotted. It is fundamental to the framework of plural rationality and works as follows (Thompson, 2008b; p 36):

Briefly, markets institutionalise equality (of opportunity, that is, not outcome) and promote competition; hierarchies institutionalise inequality (eg upper echelons/lower orders, Brahmins/Dalits) and set all sorts of limits on competition. The theory of plural rationality simply completes the typology by making explicit the other two ways of organising: equality with fettered competition (which is called egalitarianism) and inequality with unfettered competition (which is called fatalism).

Figure 2. 2D plot of the four ways of organising, according to the theory of plural rationality, in respect of perceptions of economic goods (Thompson, 2008b).

There are four ways of organising. Or, better, there are four ways of Organising and Disorganising according to the title of the companion 2008 book (Thompson, 2008a), which comes with its equally important subtitle: A Dynamic and Non-linear Theory of Institutional Emergence and Its Implications. Which "dynamic", we emphasize, directs our attention back towards what happens over time $t$, with its decision points $t -1$, $t$, and $t +1$ marking out the passage of micro time (relatively more frequently) along with the seasons of risk $T -1$, $T$, and $T +1$, co-evolving in macro time (hence marking out the passage of time relatively more slowly, in all probability). Something else, just as fundamental as Figure 2, is needed.
The four rationalities of our theory are defined and distinguished equivalently by four utterly basic and quite different perceptions of the stability-instability of the world, i.e., the specific system of interest to an insurance firm’s decision-influencer. Here they are, duly labelled essentially as when they were posited originally by their author, Systems Ecologist, C S Holling, and referred to as Myths of Nature (Holling, 1977):

(1) **Nature Benign.** The system is disturbed out of its equilibrium-cum-stasis by input $d(t)$; the system’s status or output $y(t)$ responds, specifically exhibiting an excursion away from its equilibrium (or its desired point). In a national economy we may easily conceive of GDP ($y$) responding in some way over time to a change of central bank interest rate ($d$). If $d(t)$ fades away to nothing over time — which it does, especially if one conceives of it archetypally as an instantaneous impulse disturbance, like the metaphorical cue striking the metaphorical billiard ball on the baize surface — $y(t)$ will eventually revert to the equilibrium point out of which it was originally disturbed. Indeed, to extend the ball-and-surface metaphor, such a reversion will occur when the surface is bowl-like (something from which the ball cannot escape, no matter how hard it is struck). Formally, Nature Benign is the mental model of the behaviour of a system that is unconditionally stable. No matter how much the market or the economy is beaten about, it will always return to what we have come to know and love: stasis for any abstract system in general; a steadily rising S&P 500 value for the stock market or an ever upward trend in a country's GDP. Nature Benign is the way of the world for the risk-seeking “Maximisers”; their bets will pay off. If participants in the market place adhere predominantly to the belief of Nature Benign, Boom is on the way.

(2) **Nature Ephemeral.** Here, the behaviour of the world is quite the opposite. It is unconditionally unstable. The bowl-shaped surface about which the ball moves is now upturned. Only ephemerally could the system attain a precarious stasis, at the peak of the bowl’s upturned surface. Even the very smallest of disturbances $d(t)$ — a minuscule $d$ we might write — will cause the system to crash out into disaster and failure: $y(t)$ is prone to become unbounded, a massive excursion $Y(t)$, in fact. Risk is to be avoided at any cost. Market Bust is the season; and what we call the “Conservator” type in the firm will be in the ascendant.

(3) **Nature Tolerant but Perverse.** This now is how the risk-managing type believes the world is. It is conditionally stable. The bowl-like surface is not infinitely deep. Moreover, the rim of the bowl is turned down, such that if the ball is struck sufficiently forcefully, it will be propelled up, over the rim, and out into the abyss. Disturbances $d(t)$ should surely be less than any perfect storm $D(t)$, which safe, upper-(lower-)bound limits should be discoverable and enumerated by the expert risk-managing types, the “Managers” in the company. When their candidate decisions prevail over those of the others and Nature is Tolerant but Perverse, the season of risk will continue to bloom as what they see as markets Moderate.

(4) **Nature Capricious.** The world as observed displays neither rhyme nor reason. One moment disturbance $d(t)$ will cause the system to respond
with an upward swing in its output $y(t)$; the next, that same $d(t)$ may bring about quite the opposite response. The behaviour of the asset, the market, or the system is *neither conditionally stable nor conditionally unstable*. Nothing makes any sense. The surface is everywhere flat. Struck again and again by the metaphorical billiard cue, the ball is propelled every which way across the surface, with not the slightest hint of there being some equilibrium point at which it will come to rest. The risk-absorbing "Pragmatists" have their heyday. The season of risk in the market place is Uncertain. The "old order" governing behaviour of the system in the previous season ($T - 1$) has been dismantled; the "new order", which may come to govern behaviour in the next season ($T + 1$), has yet to be assembled. But as of now ($T$ and $t$) economic affairs, or whatever, are "orderless" — all very Uncertain.

The Myths — these social constructions of Nature and the world — are foundational. They are a coherent and, so the theory goes, exhaustive set of plural ways of seeing the world (beliefs) and acting in it (decisions). They are "exhaustive", we hasten to add, when the rather special fifth rationality is also included. Historically, this fifth stance on the way the world is has been referred to as that of the "hermit". It will suffice to make just two brief observations on the hermit's stance. First, in respect of matters of the dynamic behaviour of a system, the hermit's stance has more to do with resilience over the long term (macro time $T$) than stability or instability in the short term (micro time $t$). The hermit can be said to uphold therefore the Myth of Nature Resilient (Thompson et al., 1990). Second, at the very end of this report, in Section 5, we shall suggest that the label of hermit might constructively be substituted by that of "adaptor".

In contrast to the fourfold (fivefold) plurality now introduced, the familiar duality of risk-seeking and risk-avoiding, as customarily presented or utilized, generally floats free not only of any such anchoring social-anthropological foundations but also of the coherent elaboration of so many other aspects of the world that flow from them: those of stability-instability, resilience, and the dynamics of a system; of the exercise of power among the adherents of each rationality; of the social context of each risk-coping solidarity; of fairness and justice; of the plural workings of any economy; of attitudes towards the natural environment; and even of plural styles of engineering design and technological innovation.

Given thus these more fully elaborated caricatures of the plural (four) rationalities, we are ready to enquire into the nature of governance, into that which facilitates proceeding from plural candidate decisions to the single enacted decision, and in a general sense, absent the company’s use of a foresight model, i.e., under Circumstances (C1) above.

### 3.2 Good Governance: Deliberative Quality in a Refurbished Pluralist Democracy

This, one might suppose, sounds altogether rather high and mighty (as indeed it is). Yet it is a matter of actuarial practice as much as anthropological theory. Let us put the empirical evidence ahead, therefore, of the theory.
**Plural Stances on Risk**

In our essay for the Chief Risk Officers (CRO) Council — *All on the Same Train, but Heading in Different Directions* (Underwood *et al.*, 2013) — results are presented for the analysis of risk-attitude surveys completed by some 200 insurance executives in eleven companies. Individuals, in other words, could be employed in the same company (“on the same train”), but their attitudes towards risk could be profoundly different (“heading in different directions” therefore). About half of those questioned showed a clear preference for just one of the four rationalities: 3.6% of respondents were signed up to the risk-avoiding (Conservator) stance; 9.0% to risk-seeking (the Maximisers); 17.0% to risk-managing; and 20.6% to the risk-absorbing Pragmatist position. The other half signalled a preference for five (out of the eight possible) pairwise mixes of risk-coping styles. As the largest single category of all, nearly 30% of the total sample of respondents revealed themselves to be in parts risk-seeking and risk-managing.6 Their decision strategies were blends of Maximisers-cum-Managers.

**At the Table of Debate**

The same survey showed that within the various representative groups in insurance companies (board; underwriters; management; staff) top management included the highest percentage of Maximisers and the lowest percentage of Conservators. Whether these groups were tantamount to four different “debating chambers” was not revealed by the survey. Tellingly, however — and very much so for our present discussion of good governance, deliberative quality, and refurbished pluralist democracy — the following was found (Underwood *et al.*, 2013; pp 4-5):

> When survey results were presented to one management team and it was pointed out that no one in the group favoured the Conservator culture, their response was “That would be [Joe]; he retired last year and our meetings have had many fewer arguments since then.”

There was one less candidate direction in which to head, as it were; one less base to be touched before coming to the decision; the “uncomfortable knowledge” that “[Joe]” had previously brought to the table of debate was lost; deliberative quality in governance had dropped one notch lower down; and it had become just that little bit easier to end up with group think, imposed or willed (as we have said).

Being allowed to sit at the table of debate as opposed to being excluded, having a voice and being encouraged to speak up — access, in short — and having one’s voice heard, responded to (not ignored or summarily dismissed) by those others around the table — *responsiveness* — is what pluralist democracy is all about. In its original, theoretical form (Dahl, 1989), pluralist democracy was defined as either present or absent. When absent the style of the debate was labelled a “closed hegemony”. It is that in which the one voice shouts down all the others, insists on its own framing of the problem context (the decision to be made) — which is, of course, so wonderfully well attuned to that party’s favoured style of problem solving — brooks no opposition, has its way, and goes it alone. All the others must shut up and put up. Deliberative quality in such a closed hegemony can be seen to be negligible, if not zero.

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6 Such an empirical distribution of attitudes reflects, of course, the timing of the survey and will be a snapshot of the then prevailing season of risk (Uncertain, we judge). We should expect there to be shifts in these relative proportions as the season of risk ($T$) changes (Thompson, 2018; p 10).
Deliberative Quality and Better Governance

Refurbishment of Dahl’s classic theory, driven by the need to unblock the “Reformstau” (policy log jam) then apparent in Germany and elsewhere at the turn of the century, took the theory of plural rationality and used it to elaborate Dahl’s two-domain scheme into a 3×3, nine-domain scheme (Ney, 2009; see also Thompson, 2008a,b). At that time, given that the risk-absorbing Pragmatist rationality equates to fatalism in Cultural Theory, hence seeks not to sit at the table of debate, the nine-domain scheme resulted from the participation in principle of just the three other active rationalities (risk-seeking, risk-avoiding, and risk-managing). One, two, or at most three voices could have access to the debate, delineating thus three segments along the dimension of access; and none, one, or at most two of the voices could duly respond to any given voice present at the table, i.e., three segments along the dimension of responsiveness.

For present purposes, in which the stance of the (fatalist) Pragmatist is steadily acquiring an increasingly respected standing and greater elaboration (as it is more generally, in fact), deliberative quality in the refurbished pluralist democracy can be sketched out as a 16-domain arrangement, according to Figure 3. The horizontal plane of the plot is formed by the axes of access and responsiveness, while the vertical axis represents deliberative quality. Closed hegemony, with a single voice having access and no other voice to gainsay it, achieves the lowest level of deliberative quality. As additional rationalities gain access to the debate, deliberative quality improves. Progressing along the axis of access, domain by domain, we see that ascent of the surface of deliberative quality is indicated. Likewise, as one, two, or all three of the other rationalities respond formally to the expressed position of the given voice — progressing along the axis of responsiveness, that is — the surface of deliberative quality is also ascended. Conversely, when the archetypal “[Joe]” retired from the company, governance would have slipped a domain or two down the surface of deliberative quality in Figure 3.

In practice, and this is of import for actuarial professionals, there are self-reflexive rules for grasping where lies the quality of debate and governance over decision-making in any one group in an insurance company (or among plural groups). Thus can it be discerned how to improve deliberations. It is possible for the group to pull itself up by its own boot-strap, including — now more specifically — in respect of exercising governance over model risk, hence navigating a better course (in a more resilient manner) through the cycles of the insurance market, the derivatives market, and so on.

Re-enter, then, the prospect of using a model for decision support. Circumstances become those defined as (C2) above, in which use of a model may be contemplated by all, but rejected by some of the rationalities.
3.3 Contemplating Model Risk

Phase I of the IFoA’s WP on Model Risk took the view that model risk should in due course be treated as a separate, free-standing risk in its own right, hence managed as any other risk (Aggarwal et al, 2016). It adopted the definition of model risk given in Supervisory Letter SR 11-7 of the US Federal Reserve System, which runs as follows (Federal Reserve, 2011; pp 3-4):7

The use of models invariably presents model risk, which is the potential for adverse consequences from decisions based on incorrect or misused model outputs and reports. Model risk can lead to financial loss, poor business and strategic decision making, or damage to a bank’s reputation. Model risk occurs primarily for two reasons:

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7 To be more complete, Supervisory Letter SR 11-7 was issued by the Office of the Comptroller of the Currency of the Board of Governors of the Federal Reserve System. This is abbreviated herein as Federal Reserve.
The model may have fundamental errors and may produce inaccurate outputs when viewed against the design objective and intended business uses. ...

The model may be used incorrectly or inappropriately. ...

The WP’s proposed framework for model risk management covers all those line items we would expect to find therein (Aggarwal et al, 2016): model validation; assessment of the model’s “fitness for purpose”; monitoring (and recording in an inventory) the role of expert judgement in assigning values to the model’s inputs and parameters; enumerating, recording, and evaluating the uncertainties attaching to these model attributes; establishing and maintaining inventories of software changes and updates (i.e., supervisory “change control”); imposing requirements for a “use test”, so that models may be adapted in response to feedback from the users; and, of course, governance.

As its report acknowledges, the WP saw itself as (Aggarwal et al, 2016; p 256):

building on the shoulders of existing thinking, such as the guidance issued by the Federal Reserve (2011) and HM Treasury (2013).

Yet such guidance, the WP recognised, had been silent on the (observed) fact that people (in insurance and financial businesses) have profoundly different stances on how a model’s output computations — its foresight numbers \( \hat{y}(t) \), with indeed that important, if little, \( \hat{\gamma} \) standing over the \( y \) — should inform the making of their firm’s decision, even whether a model should be used for such a purpose in the first place. The view taken was that the linkages between model output and company decision had been conveyed as excessively mechanical and rigid in the Federal Reserve’s guidance on model risk. And that was the motivation for the WP’s categorisation of people’s plural stances on models expressly according to the theory of plural rationality (or Cultural Theory). Figure 4 is the report’s less colourful version of Figure 1 (Aggarwal et al, 2016; p 257); it is also an extension of Figure 2 (from Thompson, 2008a). Its quadrature is defined by the pair of axes “confidence/concern for model uncertainty” and “legitimacy of modelling”. Significantly for our subsequent discussion of cycles and seasons of risk, it was noted that the stances caricatured in Figure 4 may be “held by different stakeholders at different times, depending on their position within an organisation and the specific processes they are involved in” — with the emphasis added (Aggarwal et al, 2016; p 257).

To chart Figure 4 in terms of our vocabulary herein, we have the following equivalences:

(i) **Individualism**, the stance of the risk-seeking maximiser (Figure 2), equates to the “Confident Model Users”, with their Rumsfeldian “known knowns”, in Figure 4.

(ii) **Hierarchy** in Figure 2, the stance of the risk manager, equates to the “Conscientious Modellers” of Figure 4, who, in line with their attachment to the Myth of Nature Tolerant but Perverse, acknowledge that there are “known unknowns”.

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8 However, as we shall observe (and address) in our recommendations in Section 5, there is evidence from practice of a different distribution of attitudes towards the legitimacy of modelling among the four rationalities.
Figure 4. The four stances of the four rationalities on the legitimacy of using a model and concern for the uncertainty associated with a model (from Aggarwal et al, 2016).

(iii) **Egalitarianism** in Figure 2 is the camp populated by those who are beset everywhere by the “unknown unknowns” of Figure 4, making them “Uncertainty Avoiders” (big time!) – the risk-avoiding Conservator types, in other words.

(iv) **Fatalism** in Figure 2 is represented in Figure 4 by the “Intuitive Decision Makers” – our risk-absorbing Pragmatists as we have referred to them – with what turns out to be their somewhat problematic “unknown knowns”.

Both the Confident Model Users (I) and the Conscientious Modellers (H) believe that models should be used to shape a firm’s decision; neither the Uncertainty Avoiders (E) nor the Intuitive Decision Makers (F) do. The archetype of the increasingly celebrated “[Joe]” – an E-type – would not want to use a model, even when available to him. As foreshadowed above when Circumstances (C2) were defined, all may contemplate the availability of the model, but not everyone will pick it up and wield it to generate foresight $\hat{y}(t+1)$.

Those in real life espousing the F stance would certainly not want to be dubbed “fatalists”. The label is absent (intentionally) from Figure 4 and, in fact, is only mentioned once in Aggarwal et al (2016) (and then in nothing more than a footnote). Nor would these types want to be exposed as “cynical” in their use of models: that (for them) models only really become useful for proving that, in the event (at $t+1$ or $t+2$ or whatever), their flawed, intuitive decisions would, in fact, have been totally supported and endorsed by the results from a model – had
that model been used at the time (at $t$). Such cynicism is empirically observed to attach to the formal rationality of Fatalism. Likewise on the negative side of the balance sheet for Fatalism, unknown knowns imply either wilful ignorance of, or the deliberate forgetting of, what was once known.

Such slurs on the stance of fatalists, however, along with their previous exclusion from the table of active debate, may not be entirely deserved. For only recently have we come across the rather positive attribute of their potential capacity to apprehend that the old order governing behaviour of the system in the previous season of risk ($T - 1$) has been dismantled, while any nascent assembling of a new order has yet to be discerned (see our introduction above of the associated Myth of Nature Capricious in Section 3.1). Added to this, control theory has long exploited the use of an active “forgetting factor” in order to enable a controller more effectively to track and adapt to a system’s significantly (and structurally) changing behaviour, as in a guided missile — what happened some time ago, it may therefore be said, is not nearly so relevant now. Furthermore, fatalism equates to the strategically important and indispensable phase of “compost” in Holling’s adaptive eco-cycle (see, for example, Thompson, 2002; 2008a). The term signals a biogeochemical state in which the basic building blocks of system structure have been released from their complex biogeochemical binding in the previously “stored capital” of an ecosystem, and are ready in principle for recombination into some new (or revived, or revitalised, past) complex structure.

**Formulae, Models, and Model Risk: The Regulators’ Perspective(s)**

As the IFoA Model Risk WP was putting the finishing touches to its Phase I Report, the Bank for International Settlements (BIS) hosted a Seminar on “Solvency and Global Capital Standards for Insurers” (March, 2016; Basel). Its Financial Stability Institute (FSI) wished to be apprised of contemporary developments regarding model risk and its management. In the event, the overall structure of the Seminar assumed the following form.\(^9\)

Day 1 of the Seminar’s proceedings turned out to have everything to do with past, present, and forthcoming standards, as presented from the perspective of the International Association of Insurance Supervisors (IAIS). In this, considerable hesitation about the use of (internal) models was apparent. The “standard formula” of Solvency Capital Requirements (SCR) was instead much to be preferred. Without any questioning or discussion, it was presumed to present no palpable “formula risk”. The inference was this. The unrecognised, but inevitable, flaws and uncertainties in, and incorrect use of, the standard formula are to be countered by a (deterministic) engineering-like “safety factor”. That safety factor is known as MOCE (the Margin Over Current Estimate). Capital adequacy requirements for insurers at decision time $t$ are accordingly to follow from considerations of the economic valuation ($V$, say) of the company. This $V$ is the risk-adjusted present value (at $t$) of the — presumably future — cash flows associated with the company’s assets and liabilities (at times $t$, $t+1$, and so on). To this valuation the MOCE is to be added, to give ($V + MOCE$) as the capital sufficient for the company to absorb significant unforeseen losses — including those (we presume) to arise from a flawed standard formula and/or its incorrect use.

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\(^9\) One of us (MBB) gave a presentation at the Seminar (on “Model Risk and Its Management: Governance and Validation”). The following is based on an informal (written) debriefing of the Seminar submitted to the IFoA WP on Model Risk in April, 2016.
Day 2, in effect, became a look into Swiss Re as an exemplary case study in how internal models are used and managed within a company. For Swiss Re, using a model (as opposed to the standard formula) is an integral part of its enterprise risk management (ERM). The company’s experience of modelling dates back to 1994. Today, in the light of Solvency II, the need for models to be used is seen as even more urgent. The view is that clients of insurance companies are much more aware of counter-party risk, i.e., the risk (here) of Swiss Re becoming insolvent. Liquidity risk management is crucial, since liabilities are relatively illiquid for insurers vis-à-vis banks. Stressed liquidity was observed to occur when markets shut down, assets cannot be liquidated, and, to cap it all, an adverse event occurs. Models, the argument runs, are therefore doubly important. They need validation protocols, change control inventories, assiduous application of the use test, and, in Swiss Re’s case, they need to be subjected to an external, independent audit. And yet in spite of all this, the risk(s) inevitably attaching to the tool that is being used to manage all the other risks — model risk, that is — was conspicuous by its absence from the day’s discussion. One could readily have concluded that models should be embraced, for there is no downside risk to their use.

Taken together, the presentations and discussions of the first two days of the Seminar can be summarized as having portrayed, albeit perhaps unintentionally, a universe of calculable numbers that are obtainable from mechanical algorithms (formulae and models) free of uncertainty.

Day 3 was built around how supervisors might intervene for the purposes of managing and pre-empting any financial instability induced by the behaviour and performance of an individual, insurance company. FINMA, the Swiss supervisor, was the focal point of this illustration. Like Swiss Re, FINMA has made a whole-hearted commitment to the use of models. Salient in this was the closing presentation of the Seminar by Philipp Keller. He is credited with being the “father” of FINMA’s Swiss Solvency Test (SST). He offered an extensive “Critical View of Risk-based Capital Frameworks”. Nearly 40 out of the total of 92 slides in his presentation refer to model risk (if not its management). Many point to the same empirical examples, case histories, and experiences of what the IFoA WP calls “models behaving badly” (Aggarwal et al, 2016; pp 229-231). For Keller, models are a “framework within which to ask questions” and to enquire into the nature of that piece of the world being modelled. They are tools, he concludes, by which “to learn as an organisation”. He well recognises the cynical use of models that we have placed in the camp of the fatalistic (F) types in the foregoing (in Figure 4). They build and use what Keller scornfully refers to as “delusional models”. In particular, he asserts, financial market risk models (but also valuation and pricing models) are “exposed to the risk [of being] set up to deliver the results that modellers or users want, rather than being calibrated to reality”. Indeed, models may even be “set up with a clearly fraudulent intent” (Keller’s words, again). For him, it all comes down to this (the very last words on the final slide of his presentation):

Rather than giving up models, models have to be managed and used appropriately. This requires a sophisticated understanding by the users of models and a continuing learning and improvement process and an adequate model risk management framework.

But let us be careful about what we should wish for! Size and a surfeit of work, as we shall see both now and later, matter.

The standard formula reflects the business of the average insurance company. Its use facilitates consistency for the prudential regulator when judgements are to be made about the solvency or otherwise of any given company in their jurisdiction. Internal models, in contrast, are tailored to the particular (non-average) business profile of a particular insurer. To make
supervisory judgements based on the results from internal models will, in principle, therefore, require more expertise and more work. Or so it was feared (by some Seminar participants): because such would be unwelcome in already hard-pressed supervisory offices, especially in the smaller jurisdictions. That which is “average”, however, smacks of the uniformity and the absence of diversity that accompany group think. It smacks too of one of Greenspan’s (2013) “human propensities” — that of coralling, if not herding — hence the potential for a system-wide, systemic risk. With an eye therefore on the stability of the global financial system, regulators in larger jurisdictions — with not only the capacity and expertise for dealing with the additional computational complexities and diversities, but also with more of the G-SIIs (Globally Systemically Important Insurers) in their jurisdictions — may encourage firms that deviate from the average to develop their own internal models.

Very strong currents of intense pragmatism are in play here. True, the use of models was under scrutiny at this BIS Seminar; and some were opting to employ them, others not. Yet the judgements being made were not taking place in the perhaps airy-lofty (transactional) realm of Figure 4 — delineated by the legitimacy of modelling versus the uncertainty attaching to models — but in some other much more immediate, visceral, monetary, personnel-cum-employment space. Model risk, of central concern to our work herein, was not being contemplated, except in the presentation made on behalf of the IFoA Model Risk WP (by MBB). Which presentation chose to focus on the likes of Figure 4 and the model cultures of Section 3 of Aggarwal et al (2016). It cast its take-home message as the abiding need for “Pre-emptive Investigatory Examination and Challenge!", i.e.:

The means to identify and flush out as many errors in the model, and (vastly more difficult) as many decision-significant omissions from it, before the event, i.e., before taking the decision at hand; as well as the means to puncture and dismember group think.

To this, the majority of the some 50 supervisors who attended this BIS Seminar (from jurisdictions around the globe) responded with puzzlement. To go beyond the standard formula, beyond even internal models and on to model risk, and then some — into not just the more familiar protocols of model risk management (use tests, change-control inventories, inventories of expert judgements, inventories of uncertainties, and so on) but into governance, and governance based on social anthropology no less — was to get into some very odd places.

But these are precisely the places we should now be getting into: to organise, orchestrate, and conduct the all-important pre-emptive investigatory examination and challenge.

**Challenge and Response Among the Plural Rationalities**

The refurbished pluralist democracy of Figure 3 suggests a 4×4 matrix of challenges. To achieve the highest deliberative quality, each stance on modelling in Figure 4 should be obliged to challenge in some way each of the three others; and each challenge should be responded to. Excluding the leading diagonal of truly reflexive “self challenge” there should — in the ideal — be a total of 12 challenge-response couples. The Phase I report of the IFoA Working Party on Model Risk fully acknowledged the gist of this, if not its expressly 12-fold structure (Aggarwal et al, 2016; p 260):

Maintaining multi-directional challenge in model risk governance ... prevents complacency and makes the enterprise more adaptable.
The report proceeded to make a significant start (see Aggarwal et al. (2016), pp 262-266). Thus, for instance, “[w]hat Conscientious Modellers need from ... and what they offer to agents with different perspectives on modelling” is drawn in Figure 5 (Aggarwal et al., 2016; Figure 7, p 263). Transparency, limitations, and structure are the headlines of how the investigation and debate should be conducted and what should be achieved. For those with an interest in the role of Systems Thinking, we draw attention to the way in which the Conscientious Modellers (the hierarchy $H$ types) frame the “box”, without which the Uncertainty Avoiders (those “emerging risk” $E$ types) would have nothing outside of which to think. Technically, we conjecture, there should be three other versions of Figure 5, one each for the Confident Model Users ($I$ types), the Uncertainty Avoiders, and the $F$ types.

While the IFoA WP never proceeded that far, the merits of such a fourfold plurality of challenge-response couples — and the company forum or “debating chamber” in which they should be discussed — should in due course be examined. The nature, content, and empirical validity of Figure 5 were (subsequently) investigated, however.

![Figure 5. Organising challenge and response in debate among the plural stances on the legitimacy of using a model in actuarial practice (Aggarwal et al., 2016).](image)

“People Like Us” — Primus Inter Pares?

When it comes to using models, there is something rather laudable (is there not?) about those who acknowledge the “known unknowns” of the situation and examine their consequences, deliberately through various exercises with their models. That is what uncertainty and sensitivity analyses (UASA) have been all about. These Conscientious Modellers are indeed “people like us”, as actuarial scientist Tsanakas observed on one occasion (in 2015) to the assembled members of the IFoA WP. Some of us (MBB at least, that is) have long sat in the Conscientious Modellers camp, unaware until quite recently that our (limited) outlook on the world of models was that of the hierarchical $H$-type characters. We (they) are not *primus inter pares*.

And yet it is precisely from this camp, argue Tsanakas and Cabantous (2018), that the concern for model risk emanates, specifically in the form of the supervisory note from the Federal...
Reserve (2011), an institution one may readily view as the archetype of hierarchy (likewise the origin of the companion guidance from HM Treasury (2013)). In introducing their empirical study of governance for coping with model risk — based on interviews with some 31 practitioners in the London insurance market — Tsanakas and Cabantous (2018) present an amplified and (significantly) re-oriented version of Figure 5. It appears here as Figure 6. In this they place “people like us” at the centre — primus inter pares — with the stances of the other three rationalities triangulated around “us”. They write of Cultures of Model Use (CMUs) and, in the light of their revised version of Figure 5, observe that the notion of model risk is the product of one particular one-way challenge: a critique of the Individualist (I) stance, with its known knowns, by the Hierarchist (H) stance, with its known unknowns, which they see as follows (Tsanakas and Cabantous, 2018):

The relationship between Individualism and Hierarchy is characterised by a trade-off, corresponding to the respective concerns of the associated cultures of model use: between expanding the model’s use in business decisions (Individualism) and limiting its use to those applications for which the model is deemed fit-for-purpose (Hierarchy). Notably, the Federal Reserve’s (2011) guidance places a heavy emphasis on the fitness-for-purpose of quantitative models, argues for the use of prudent modelling choices in the face of uncertainty, and cautions against using models outside their design scope. While acknowledging that excessive conservatism can become an impediment to model development and use, the guidance clearly states that limits should be placed on model use, if sensitivity to model outputs is high when inputs, such as statistical parameters, are slightly varied.

Figure 6. Further development of how to organise challenge and response, triangulated around but the one stance of the Conscientious Modellers, denoted “hierarchy” (Tsanakas and Cabantous, 2018).
Such interaction between the two rationalities (Individualism and Hierarchy) is as that identified elsewhere — in the (US) National Research Council book (tantamount to a code of best practice) on *Models in Environmental Regulatory Decision Making* (NRC, 2007) — between the Sound Science Analysis (SSA) of a world of known knowns and the Deliberative Problem Solving (DPS) of instead a world of known unknowns (as discussed more fully in Beck, 2014). If the conception of model risk is aligned with just this single one-way challenge — issued by people like us to but those modelling-besotted fanatics — this is both much too narrow and something beyond which governance in ERM must go (Tsanakas and Cabantous, 2018). In the London insurance market, at least with respect to the use of internal capital models (as a consequence of Solvency II), the evidence suggests practitioners are not behaving at all “narrowly” in this way.

Narrowness, however, may come in more than one guise (Tsanakas and Cabantous, 2018):

A further issue, not addressed in detail here, is related to the potential dangers engendered by the widespread use of increasingly similar quantitative models, in terms of structure and parameterisation, due to homogenising regulatory feedback and reliance on a small number of external proprietary models (Catastrophe Models and Economic Scenario Generators). The spectre of such systemic model risk clearly worries our respondents in the London market; possible flaws in those models could mean that the market may collectively underestimate (or even remain unaware of) particular risks ... And this is a worry to others too (Heinrich et al, 2019; p 1):

Under Solvency II, insurance companies are required to use only certified risk models. This has led to a situation in which only a few firms provide risk models, creating a systemic fragility to the errors in these models.

Our results suggest that it would be valuable for regulators to incentivize model diversity.

One can sense some inadvertent herding in this — some corralling of behaviour into a more confined space — if not the unfettered, instinctive workings of those animal spirits of Keynes or those human propensities of Greenspan (2013).

**Systemic Risk**

If the world can be seen as comprising a host of almost endless archetypal trios of subsystem, system, and supra-system, the system is for us herein primarily the individual insurance firm. From this perspective, some of the thereby defined environment surrounding the cut-out firm (the part) may be considered the supra-system i.e., the insurance industry and its markets as a whole. The outgoing ramifications of decisions made by the single firm disappear (technically) into the supra-system and come back in the form of incoming “disturbances” to the firm, emanating not least from what it perceives as its risk environment. The system of the firm is the focus of our work. The supra-system of the industry as a whole is the focus for Heinrich et al (2019). They call their study “A Simulation of the Insurance Industry: the Problem of Risk Model Homogeneity” (Heinrich et al, 2019). Their computational analyses demonstrate the (familiar) virtues of the principle of diversification, which is crucial to us too, but in a form

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10 The jibe levelled at Sound Science Analysis in the domain of environmental protection (as opposed to financial loss protection) is that models are taken to be “truth-generating machines” (Beck, 2014; pp 110-111).
and at a scale different from the setting of our own research (into governance and rational adaptability).

The model of Heinrich et al (2019), like the Surprise Game, is an agent-based model (ABM). In it, however, simulated company decision-makers (the principal agents) avail themselves of the outputs of up to four simulated foresight models, each of which is flawed — so there is indeed here a “model within the model”. The simulated agents, therefore, are guilty of the first of the two types of error that give rise to model risk, of using a flawed model, but they are innocent of the second type of error, of using the model inappropriately. The (simulated) models available to the (simulated) decision-makers are catastrophe risk models intended to forecast risks arising from natural catastrophes (such as flooding events) in four geographical regions of peril. Four such models are available to the decision-makers. Each model underestimates the risk of a catastrophe in one of the four peril regions and over-estimates it in the other three regions. Within the ABM, the simulated foresight model error is treated as a parameter of the ABM. To be clear, it is one of those things we would denote herein as a parameter $\alpha$ of the ABM, not a parameter as such of the simulated foresight model, embedded as it is within the ABM. Technically, it is a multiplier denoted as $\zeta$ in Heinrich et al (2019; p 11), whose value is typically either 0.5 (for under-estimation of the simulated catastrophe risk) or 2.0 (for over-estimation of the simulated catastrophe risk). The simulated agents work in a set of tens of simulated insurance and reinsurance firms. The decisions they make are twofold (Heinrich et al, 2019; p 11):

- whether or not to underwrite a contract based on whether their capital ... can cover the combined value at risk of the new and existing contracts in the peril region with an additional margin of safety ... [and] additionally ... to maintain a diversified portfolio with approximately equal values at risk across all ... peril regions.

In short, the benefits of diversifying away from the use of just the one model — of here using up to four of them — are of the nature of, for example, fewer large bankruptcy cascades across the supra-system of the market for insuring and re-insuring against natural catastrophe risks.\footnote{11} More simulated firms survive, the more simulated foresight models their simulated decision-makers avail themselves of.\footnote{12} Yet do such features vary as a function of the magnitude of model error-risk, i.e., parameter $\zeta$? The authors record the fact that they have conducted such tests of sensitivity, but not their outcomes (Heinrich et al, 2019).

Our interests too are likewise in having diversity (as in touching plural bases), but in the process of proceeding from plural sets of candidate decisions to the actual decision in one company. To begin with, our interests are even in maximising diversity when decision-influencers within the company are availing themselves of just the one (flawed) model, which would seem (on the surface) to be deeply redolent of the kind of closed hegemony with the lowest of deliberative quality in governance. Ergo, we come to address model risk and governance under the third category of Circumstances (C3).

\footnote{11}{The supra-system addressed in the ABM is thus not quite the entirety of the insurance industry.}

\footnote{12}{These results, we presume, are subject to there being but a single simulated decision-maker in any given firm. The fact that s/he employs a model to shape a decision and, moreover, is fully open to consulting two or more models, conveys the distinct impression of this simulated individual being of the hierarchical $H$ type who recognises the known unknowns — one of us, in fact!}
3.4 Exploiting the Foresight Model to Elevate Deliberative Quality in Governance

What then is our framework for exercising governance in respect of model risk starting to look like? What are its basic components?

At bottom, at the very origin of things, stands the fourfold typology of the theory of plural rationality, which is to say, the set of four Myths of Nature, which in turn is to say, the four social constructions of nature advanced by systems ecologist Holling (in the 1970s). The typology may be plotted as the 2×2 matrices of Figures 1, 2, and 4. Two axes define a so-called transaction realm: about the decision-making style of insurance-company personnel (Figure 1); about the nature of economic goods (Figure 2); about the nature of the knowledge deployed in a model (Figure 4); and so on. Strictly speaking, each entry in the matrix depicts a perspective on the world that derives from one of the four pairwise combinations of the two polar attributes of the dimensions of the axes creating the quadrature of the plot. Thus, for example, in Figure 4, the upper left quadrant denotes the location of those who (a) do not believe in the legitimacy of using a model and (b) are confident about their knowledge of what will happen next in the world.

On the foundations of the fourfold typology may be built the second essential component of our emerging framework: the more refined (refurbished) segmentation of deliberative quality in governance (Figure 3). Given four stances on, say, the use of a model to support decision-making in an insurance company, there is the possible refinement of a 16-fold segmentation of the surface of deliberative quality, where the sixteen derives from, on the one hand, the devotees of one, two, three, or all four stances (on the use of a model) being present and delivering their viewpoint at the table of deliberation and, on the other hand, none, one, two, or three of the “listening” stances responding to what each “speaking” stance has said.

The third core element of our framework has to do with organising and implementing challenge and response according to the 12-way couples of “speaker” and “listener”. How, for example, might the framework of the notional company debating chamber better orchestrate the dialogue that should follow from the objections laid at the door of people like us (the Conscientious Modeller (H) types in Figures 1 or 4) by the Uncertainty Avoiding E-types? Indeed, how should this better be orchestrated with a view to proceeding from plural candidate decisions to the single, subsequently enacted, decision?

What emerges from the existence of these three basic components is that sense of diversity in sharing risks, in distributing liabilities and assets, and in outlooks on the ways of the world and acting in it. This is nothing more nor less, of course, than that which is defining for the insurance industry. The cultivation and pursuit of diversity are what we have just seen promoted as virtuous in avoiding systemic risk in insuring against natural catastrophic events. Ours, however, is a very particular kind of organised cultural diversity. It is bounded by its basis in just a fourfold typology. Even so, as we have already warned, we must be careful about what we wish for. For we shall see that just this fourfold basis can readily lead to combinatorial possibilities for exercising diversity.

Sensitivity Analysis: The Local, the Regional, and the Cultural

Consider we have just the one model: one model structure with parameters $\alpha$. We have a candidate decision at decision time $t$, which (following one kind of control theory house-style)
we will now label as $u(t)$. The purpose of sensitivity (and uncertainty) analysis is to examine the possible consequences of this candidate $u(t)$, in respect of what we value about the system’s behaviour (its outputs $y(t)$), in the event that the model’s parameters are not as we have enumerated and assigned them to be.

Local analysis of sensitivity takes the assigned set of point values of the parameters — let us label this set $a_0$ — and evaluates what happens to $y(t)$ in the event that one or more of the parameters should have a slightly different ($\delta a$) value, i.e., the model’s parameters are assigned as $(a_0 +/− \delta a)$. If the resulting changes in $y$ are minor and judged to be inconsequential, it may be concluded that candidate decision ($u$) is a promising and robust choice. Typically, the analyst is alert to $y$ being significantly, if not substantially, different, in which case the candidate decision is judged to be prone to model error, especially when $\delta a$ is indeed but small.

What has been called a regionalised sensitivity analysis (Young et al, 1978; Hornberger and Spear, 1980; Spear and Hornberger, 1980) works instead with spans of assigned values, as opposed to point values $(a_0)$, for the model’s parameters. Let us denote these spans simply as $[a_l ↔ a_u]$, wherein subscripts $l$ and $u$ denote the lower and upper bounds respectively on the allowed values that may be assigned to the parameters, while $↔$ signals the fact that the parameters may assume any value within the thereby bounded span. Again, the analyst must be alert to observing whether any of the outcomes ($y$) from implementing the candidate decision ($u$) might veer into becoming unacceptable, subject to the uncertainties in the model as reflected in the $[a_l ↔ a_u]$. It is not hard to intuit that the results of a regionalised sensitivity analysis would indicate that a robust candidate decision is relatively more robust than any companion conclusion emerging from the local analysis of sensitivity.

A cultural analysis of sensitivity, as far as we know, is here being defined for the first time, as follows. Our four rationalities, with their dramatically different ways of seeing the world, would each parameterize the model to suit its own stance. In other words, we could have four quite different sets of numerical values assigned to the model’s parameters: $a(I)$ for the individualist, risk-seeking, maximiser ($I$) type; and likewise $a(H)$ for the $H$-types, $a(E)$ for the $E$-types (the “[Joels]” in the company), and $a(F)$ for the $F$-types. Accordingly, whereas the local sensitivity analysis touches but one base ($a_0$), as it were, a cultural sensitivity analysis would touch the four bases — $a(I)$, $a(H)$, $a(E)$, and $a(F)$ — before the company proceeds to enact its eventual singular decision. In addition, the juxtapositions of the four bases ought ideally to be as separate, distinct, and different from each other as possible, within the space of the values that may be assumed by the model’s parameters. They should be “culturally pushed apart”, we may say. Moreover, such a cultural analysis of sensitivity could come in a relatively local and a relatively regionalised form. However, to define this more tightly would lead us into using some notational algebra that some readers could find rather indigestible. Furthermore, to be faithful to our theory of plural rationality, each such cultural test of the model should have a candidate decision $u$ — born of the given rationality’s distinctive risk-coping style — that is consistent with its choice of the $a$ to be assigned to the model.

But wait a minute, the astute reader should protest: whose then should be the one model we have presumed to begin with? To which one might be tempted to respond, let there be plural

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13 Besides, we have already used $d(t)$ for system disturbances.

14 And likewise, in fact, with respect to the assumed disturbances $d(t)$, and possibly $d(t+1)$ and so on into the future.
models: four quite differently structured models, each with its perhaps utterly different parameterization. Diversity, we could then appreciate, would be beginning to burgeon by leaps and bounds. Yet given the (purported) implacable opposition of the \( E \) and \( F \) types to the use of models (Aggarwal \textit{et al.}, 2016), would they — in the absence of their own models — even tolerate others (the \( I \) and \( H \) types) using an \( \alpha(E) \) or \( \alpha(F) \) parameterization of their respective two \( (I \) and \( H) \) models in the names of the \( E \) and \( F \) types? Given too that trust must be vital to enhancing deliberative quality in the firm’s governance of model risk, such questions are crucial.

**Inverse Analysis of Sensitivity**

It is customary to conduct an analysis of sensitivity in what we shall call an open-loop “forward” manner. In other words, we stand at decision time \( t \), ever on the threshold of the future, and we test how the consequences of a decision may change significantly the nominal estimate of whither the system might be headed, towards \( (t + 1) \), if not beyond — for example, in the shape of the firm’s future financial status. The foregoing introduction of the three forms of sensitivity testing refers to this kind of analysis.

Putting ourselves in the shoes (or in the head) of a member of any one of the camps of culturally differing and sharply opposed stances on the problem at hand, we are asking this:

**Forward Question**

If I entertain the possibility of my beliefs about the way the world works being flawed, will my preferred outcome of my candidate decision, when applied to the system, be undermined in any way?

There is a complementary inverse question.

Once again, we stand at decision time \( t \) on the threshold of the future. Here, however, a novel ingredient is incorporated into the questioning and analysis: it is the expression of aspirations for, and/or beliefs about, the future status of the system (towards \( t + 1 \), if not beyond). The testing of sensitivity may then be cast as a matter of contemplating the attainability — or “reachability” — of expressly defined possible future states of the system. The intent is to identify upon which risk factors and parameters in the model such reachability of these expressed futures crucially hinges. In contrast to the open-loop nature of a forward analysis of sensitivity (above), we may describe this as a closed-loop form of sensitivity analysis. Something about the match/mismatch between the numerical predictions of the foresight model and the firm’s future aspirations is fed back. In this case, the archetypal fanatic with her/his distinctive rationality should be asking something like this:

**Inverse Question**

Given my (strong) aspirations and preferences for where I want the system to be in the future — or where I just as strongly believe it will actually be (irrespective of my wishes) — upon what knowns and/or unknowns in my

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\(^{15}\) It is, of course, hard to imagine the “fanatic” — one utterly convinced of her/his being right — asking this of themselves.
present beliefs about the way the world works might the “reachability” of my so defined futures (preferred or actual) pivot?

It was in fact this kind of closed-loop, feedback form of question that prompted the original formulation of the (now capitalized) Regionalised Sensitivity Analysis (RSA) introduced above (Young et al, 1979; Hornberger and Spear, 1980; Spear and Hornberger, 1980).

Speaking technically (before later speaking more colloquially), RSA is founded upon acknowledging and tolerating the possibility of gross uncertainty in the quantitative, numerical expression of future aspirations (hopes and fears), say \( y_A \) — because what drove its invention was the opportunity and need its authors had spotted for exploiting empirical personal experience of the behaviour of a system, largely in the absence of conventional numerical observations or data. The method also tolerates gross uncertainty in the assembly of the model, i.e., in its \( \alpha \). Monte Carlo simulation is used to generate an ensemble of model outputs, i.e., the system’s estimated outputs, \( \hat{y} \). Whether, and which of, these \( \hat{y} \) fall within the span of the future aspirations-beliefs \( y_A \) (or not) are then determined; and each candidate model parameterisation \( \alpha \) (in the Monte Carlo simulation) is accordingly classified as to whether it “gives” the expressed future behaviour or not. The Kolmogorov-Smirnoff test statistic is then employed to gauge the degree of separation between the \( (a \text{ posteriori}) \) behaviour-giving and not-behaviour-giving distributions of the thus classified model parameterisations. Where there is significant such separation, this subset of model parameters is concluded to be key to the reachability of the expressed futures. It matters, and vitally so, what specific kinds of values these parameters may assume. For they have the potential to discriminate between whether one’s fears or one’s hopes are realised. Where there is no such separation, the associated subset of model parameters is deemed to be redundant in respect of the reachability or otherwise of the expressed futures. It matters not a jot what particular values such redundant parameters may assume. More or less one and the same value may happen to generate the hoped-for future, or, just as likely, the nightmare.

Pragmatically, the intention of RSA is to unearth but the handful of key parameters — key risk factors, key current unknowns (or knowns) — on which effort, time, and money should spent in research, all the better to understand their potential impacts on the performance of (herein) the insurer in the future. For there is neither the time nor the money to chase down whether all “1,001” unknowns in the model might all be important, or not.

The empirical record of RSA being employed to address the inverse question (or, much more frequently, as it happens, like questions) is quite long. First proposed in the late 1970s (Young et al, 1978; Hornberger and Spear, 1980; Spear and Hornberger, 1980), its conceptual and computational simplicity made it not only an immediate success (see, for example, the review of Beck, 1987) but also, in retrospect, an abiding framework for reasoning about potential ways of “resolving” recalcitrant model-related problems (hence these remarks about it). Indeed, closer to the truth, and oddly much in the spirit of Systems Thinking, it is a solution framework that has given birth to rather interesting problems. Or put another way, it has been a framework for generating answers in principle (A’s we might say) that has provoked the conception of challenging questions (companion Q’s), often ones not previously asked. And it has worked in this way not in the unproductive (but familiar) spirit of a solution in search of a problem. For instance, it appears as the means to assure the quality of models designed for predictive tasks in one of the standard, general textbooks on Sensitivity Analysis (Saltelli et al, 2008).

16 And this closed-loop, feedback form betrays the even deeper intellectual origins of RSA in control theory. Two of its three authors, Spear and Young, are control engineers.
2000; as Chapter 21, Beck and Chen, 2000). It has been instrumental in prizing open ways of thinking about generating foresight in the presence of structural change, when the behaviour of a system may be experienced in the future as profoundly different from anything ever observed in the past (Beck et al, 2002a). In fact, to this we shall return, albeit briefly, towards the end of Section 4 below. Elsewhere, way-markers along the path of development to the cultural sensitivity analysis introduced above (inspired by the conceptual structure of RSA) can be found in Beck et al (2002b) and Osidele and Beck (2003, 2004). In its complete form, the procedure embeds what we shall refer to as an analysis of “reachable futures” within what has been called Adaptive Community Learning (Beck, 2011; Chapter 4, pp 83-102). And this, given its name, is unsurprisingly little distant from the focal topic of the next Section: Rational Adaptability.

To appreciate the difference between the forward and inverse analyses of sensitivity, in a hugely simplified illustration, let us borrow from an example presented by Swiss Re at the March (2016) BIS Seminar. The imagined spur to the pre-emptive examination with ICAM (Swiss Re’s internal model) was substantial, a €40B loss. This, it was said, would surely attract the attention of the Board. In a forward questioning mode, joint risk factors (matters having to do with the parameters $\alpha$ of the model) would first be assembled, for instance, as probability distributions presumed \emph{a priori} for the joint occurrence of, say, the German DAX dropping by 5%, the 10-year € Swap Rate declining by 20 basis points, the Ford Motor Company rating being set at BB+, and so on. Then, second, the model would be run, in the manner of a Monte Carlo simulation, and — should a €40B loss happen to be generated (as an output $y$) — the precise details of the corresponding (but randomly realised) parameterisation of the model would be unpacked, scrutinized and heeded, or ignored. In an inverse analysis, the first step is to define the numerical $y$ of the nightmare outcome, a loss of more than €40B (and its logical complement “not-the-nightmare outcome”, of losses less than €40B). Second, having undertaken the Monte Carlo simulation and employed the Kolmogorov-Smirnoff test statistic to discriminate between the key \emph{a posteriori} risk factors (model parameters $\alpha_K$, say) and redundant \emph{a posteriori} model parameters (risk factors $\alpha_R$, say), the company Board would ask itself this: what do we really have to worry about (Brexit or the Ford motor company or whatever); and what risk factors should we remain aware of, yet not treat as mission-critical?

\textbf{Mobilising Diversity in the Service of Governance}

Speaking colloquially, how do sensitivity and uncertainty analyses for answering the inverse question add to the exploitation of cultivated diversity in the service of governance for guarding against model risk? How do they contribute to what was referred to in the BIS Seminar presentation as pre-emptive investigatory examination and challenge? How might they enhance the kind of disputatious challenge-response framework first set out in Aggarwal \emph{et al} (2016) and subsequently elaborated in Tsanakas and Cabantous (2018)? We point to but one thing.

In contrast to the forward, open-loop form of sensitivity analysis, plural rationality is manifest in two places in the preceding inverse question: in the plural, mutually opposed beliefs about the mechanics of the way the world works (as embedded in the foresight model) and in the plural, mutually opposed preferences and aspirations for the future. Cultural diversity may thus explode from 4 to 4×4, just like that! For we can imagine this. In respect of the hierarchist, risk-managing, $H$-type “people like us”, the foresight model may be parameterised through “our” $\alpha(H)$ and implemented in the RSA. “Our” $H$-type model may then be challenged to inform us of which of those model parameters — the $\alpha(H)$ — are key (redundant) in determining the reachability (or otherwise) of not only “our” own manager-style aspirations, “our” $y_A(H)$, but
also the Conservator-style aspirations of the risk-avoiding $E$ types — “their” respective $y_A(E)$ — and, in turn, the aspirations of the other two rationalities, as encoded in “their” respective $y_A(I)$ and $y_A(F)$. Expressed the other way around, the foresight model may be parameterised not according to the way the risk-managing $H$ type perceives the world, but according to how the maximiser $I$ type does, i.e., through $a(I)$, or the $F$ type, with her/his $a(F)$, or the $E$ type’s $a(E)$. And so on, thus to exhaust all the $4 \times 4$ pairwise combinations of beliefs and aspirations.

In fact, such a combinatorial profusion of diversity is starting to look a bit bizarre, if not plain inconsistent in its logic. For what exactly would it mean for some of the risk factors and parameters within the $H$-type’s “bag” of beliefs about the way the world works to be found to be key (redundant) to the reachability of the $E$-type’s aspirations? In addition, that (tacit) presumption of just the one structure of foresight model is once again troubling to our reasoning, as follows. Suppose each rationality indeed insists on exercising and testing solely its own model structure. That which it can then identify as key/redundant to the reachability of its aspirations must accordingly be restricted to those risk factors and parameters it chooses to put into its bag of model parameters. And needless to say, the contents of this bag of potentially mission-critical factors may be very different from the contents of the bags of the other (three) rationalities.

Notwithstanding the fact that the whole point here is to probe and to challenge — especially wherever group think may lurk — we caution again that we should be careful about what we wish for. Time-consuming computational exercises in exploring all the conceivable diversity, if not astutely managed, may come to undermine the practical value and timeliness of this emerging fusion, of RSA with inverse questioning and with plural rationality. We touch upon this in our recommendations for future research in Section 5.

More immediately, our discussion has arrived at a point of transition, between governance for managing model risk (this current Section 3) and model support for rational adaptation (in Section 4). In a sense we are en route from RSA to guided missiles (of all things), and from there to feedback control.

### 3.5 Actuarial Science: From Our Anthropological Hypothesis and Towards Some Control Conjectures

In our introductory discussion of the inverse question neither of the following possibilities has been apparent: that the (presumed) future incoming disturbances of the system, the $d(t)$, may be parameterised (in effect), as may each rationality’s candidate decision $u(t)$. In other words, under an RSA, we may pose the likes of these further questions: just exactly what patterns of future disturbance, or what kinds of decision formulation, might be key (or redundant) to attaining our aspirations? The scope of the diversity available to us, within the model and the way we exercise it, may readily be thereby yet further extended.

#### Parameterizing the Feedback: Direct and Circuitous

In particular, given the way in which control theory has been seeping steadily into the words, vocabulary, notation, and phrasing of this report, and the way in which RSA, with its closed-loop feedback form, betrays its origins in control theory, consider this. What is to be decided at time $t$ — and what is to be decided at future decision points $t + 1$, $t + 2$, and so on — can be made a function of some measure of the mismatch between what is wanted of the system’s behaviour (redolent of the $y_A$) and what that behaviour actually is, or is forecast to be (redolent
of \( \hat{y} \). Something about the output side of the system may be fed back — through a control rule — into something (decision \( u \)) that is applied to the system on its input side. The feedback loop is closed. Without at this stage venturing further into the details of any principles of feedback control system design, we note that decision \( u \) is typically formulated as the product of a proportionality constant, often labelled a \( k \) in classical control theory, and measures having to do with the (output) mismatch (cast in terms, in some way, of the \( y \)). And, of course, a constant or parameter \( k \) embedded in the model may be just as subject to an examination of its “mission-criticality” as any other more familiar parameter (an \( a \)), even, we speculate, a cultural sensitivity analysis thereof (of \( k \), that is).

Feedback control in control theory, however, is intended to be of the stabilising negative variety. Input decision \( u \) is formulated to counter undesired excursions in the system’s output \( y \) by seeking to bring about consequences for \( y \) that work in precisely the opposite direction to that of the unwanted deviation. The feedback loop is intimate and direct with respect to the system of interest, i.e., an insurance firm. Something about \( y \) goes straight back to something about \( u \).

Instability, in contrast, tends to be associated with the positive kind of feedback flowing around the loop. But it is quite counter-intuitive to suppose it would be used by design in the insurance firm, i.e., that decision \( u \) is chosen to bring about consequences for output \( y \) that deliberately add to and amplify the unwanted excursion on which \( y \) has already embarked (although, of course, one rationality’s “unwanted” could well be another’s “desired”). Positive feedback loops, in the specific instance of the insurance firm, may be more likely to be lodged in places outside the system, in its risk environment, in the supra-system of the insurance industry as a whole, for instance. When discussing systemic risk above, we commented on how the outgoing ramifications \( y \) (of decisions \( u \) made by the individual firm) may disappear into the supra-system and come back in the form of incoming disturbances \( d \) to the firm. In fact, Heinrich et al (2019) make the assumption that their simulated insurance and reinsurance firms are not price setters, with their carefully thought-out \( u \), but “price takers”. Arguing that the insurance industry is highly competitive, premiums for any given company’s catastrophe insurance products are determined by the total amount of capital in the market, to which each firm contributes by its own actions. Which is to say that an individual insurer’s product premium rate is not all that fully controllable, but instead markedly subject to what goes around and comes back around from the supra-system, to impinge thus on the insurer system as a disturbance \( d \) from its surrounding environment.

It is not hard to imagine a potentially destabilizing element — of herding, for example — being carried around this outer, circuitous feedback loop. This too would be feedback — between the firm’s past \( y \) and its current \( d \) — of a much less intimate, less close-by, less immediate character. Indeed, and this is very important, it may well be significantly delayed in time. The supra-system-wide ramifications of the individual firm’s outgoing performance today, \( y(t) \), may return to shape that same firm’s incoming disturbances at future time \( d(t + \Delta t) \), where \( \Delta t \) is the time delay or, in control speak, “dead time”. And (pure) dead time is one of the trickiest of features in the dynamic input-output behaviour of a system to cope with in designing control systems. It will re-surface very shortly in what we shall say of actuarial practice.

Might then it even be worth parameterising this kind of \( y - d \) feedback in the foresight model, to shape somehow the form of \( d \) to be in part a function of \( y \) — and to examine the mission-criticality of these other, perhaps more tenuous, (feedback) parameters too? But what would be the question? Could it be of this kind: How much herding “out there”, or copy-cat emulation of our success, can our firm tolerate?
Classical and Modern Principles of Control

Where there is “classical” control theory, as we have called it, so too must there be a body of “modern” control theory — for why otherwise would there have been a need historically to qualify all previously existing theory as “classical”? Classical control theory, on the cusp of transmogrifying into the modern control theory of the 1970s, has already been applied to actuarial science and practice. This we now review, as we proceed to our discussion of the design and use of models for supporting the implementation of Rational Adaptability in ERM. For it was modern control theory that gave rise to the principles and algorithms of adaptive control, spurred on, as they were, by the development of guided missiles in the 1960s. It was the (on-board) controllers in these missiles that may once have benefited from forgetting factors, so that their embedded system model could all the better be adapted, to create continuously a very good “snapshot” of the current, but substantially changing apparent structure of the system’s dynamic behaviour. It is a benefit we have ascribed above to those of a fatalistic-like persuasion, with their unknown knowns; and that would surely be something of a “make-over” for $F$ types.
MODELS AND RATIONAL ADAPTABILITY IN ERM

What exactly is this thing called dead time ($\Delta t$)? As a matter of the very simplest of palpable, everyday experiences, it is this: that which, in concert with our personal control actions (duly confounded by the dead time), causes us to be “frozen” and “scalded” alternately in a bathroom shower whose head is some distance from the reservoir of hot water.\textsuperscript{17} If we confine our attention to the length of pipe conveying the water from A to B, we may define its input $d(t)$ as the temperature of the water entering the pipe at location A. It will take the elapse of the dead time $\Delta t$ before any change in the incoming water temperature is sensed as an output change, $y(t+\Delta t)$, in the water emerging from the pipe at location B. In fact, to make matters yet more complicated (not least for the design of shower temperature-control units), the dead time itself may vary with time $t$ as a function of the rate of flow of water demanded downstream of the conveyance pipe (beyond B) and drawn into it from upstream of A. One can readily appreciate, therefore, why dead time is referred to alternatively as a “transportation lag” in chemical engineering systems.

That said, reflect on the word “alternately”, down and up, in the foregoing. It implies the origins of oscillations; and oscillations are the logical basis of cycles, even instability. Now recall that governance for guarding against model risk is one of our two primary concerns (and the preoccupation of the foregoing Section 3). Consider then that the risk of a model forecast being seriously in error will be greatest around the turning points in a cycle. None of the illustrations of models behaving badly in the Phase I report of the IFoA Model Risk Working Party (Aggarwal \textit{et al.}, 2016), however, refer to the use of models in navigating the dynamics of any insurance or market cycle. In addition, such qualitative shifts in a firm’s risk environment — turns indeed in what we have been calling the seasons of risk — are precisely what gives rise to the need for Rational Adaptation (RA), which is our second primary concern, hence the subject of this present Section 4. Furthermore, what is crucial in practising RA is to enact the adaptation of the firm’s decision strategy with the minimum of dead time (that $\Delta t$ again) as the firm goes through the process of being surprised into apprehending that the season of risk has, in fact, changed.

But we have jumped ahead to the closing discussion of this Section. Besides, dead time is not the only source of cyclical behaviour and instability in a system, but it does make controlling a system quite a challenge. Which is where our approach to RA will begin, with the seminal work of actuarial scientist Bernard Benjamin and control engineer Les Balzer, whose collaboration began in 1970/1, when so-called modern control theory was emerging from the corpus of its (therefore) classical precedents (Section 4.1). Their concern was to suppress oscillatory behaviour and incipient instability in adjusting an insurer’s premiums in the face of dead time in the claims processing loop and estimation of the company’s accumulated surplus. Two further case studies in the application of more advanced and more modern methods of control system synthesis to the Benjamin-Balzer problem are then reviewed (Zimbidis and Haberman, 2001; Yang \textit{et al.}, 2016), before the original analyses of Benjamin and Balzer (1980) are formally — and very readily — connected to Clark’s (2010) work for the Casualty Actuary Society (CAS) on “Creating a Market Cycle” (Section 4.2).

With the question of what causes an economic cycle centre-stage, our discussion transfers from control theory to the social anthropology of a case study in understanding the causes of

\textsuperscript{17} Granted, however, such an experience might now be a thing of the past, for those fortunate enough (that is) to have had access to a bathroom shower before the plumbing, mechanics, and electronics of their temperature control system were modernised.
a “trade cycle” in a ceremonial gift-giving culture among Enga pig breeders in New Guinea (Section 4.3; Thompson, 1979). Such a perhaps startling cross-disciplinary segue between, in effect, our control conjectures and our anthropological hypothesis about actuarial science is mediated largely by the latent action (herein) of the catalyst of catastrophe theory (close cousin of control theory). Indeed, this is what knits together our two disciplinary strands, of some control conjectures and our anthropological hypothesis. It turns out that this “pig cycle” can only be properly explained if we permit ourselves to mobilize two key presumptions. First, Keynes’ fundamental psychological law accounting for the role of individual human motivation in his economic theory must contain a proportionality constant (a marginal propensity to consume; and an $\alpha$ no less) that varies with time, i.e., is “in truth” an $\alpha(t)$. And second, initiation of the abrupt and surprising downturns in the pig cycle is sparked by a discrete switch in the operative rationality of a pig-breeder’s decision-making, from being an $I$ type to being an $H$ type. Such a swapping out of one way of seeing the world and acting in it for another is, in effect, a very early forerunner of what subsequently was expressed of the theory of plural rationality in the 2008 article on “Beyond Boom and Bust” (Thompson, 2008b) and in the set of six articles on RA published in the *InsuranceERM* Compendium (2009-2013).\(^\text{18}\)

It is then but a short and smooth step from the pig cycle into the domain of RA and our seasons of risk (Section 4.4), hence our first exploration of model support for RA (Section 4.5). And in this latter we do not shrink from drawing the parallel between what is at the heart of the adaptation in RA and what has been studied at considerable length over several decades as *structural change* in the dynamic behaviour of a system (Beck, 2002). It will get us (we warn) into something from control theory that is really quite sophisticated mathematically yet conceptually so very elegant. It will be something we may store up for future possible developments!

### 4.1 Our Control Conjectures

Forty years before the conjunction of social anthropology with actuarial practice (with which this report began, in Section 1.2) a similar exercise in cross-disciplinary Systems Thinking was completed. It married actuarial science with control theory. As far as we can establish, it has been but little heeded since. It is illuminating, therefore, to recount significant parts of it.

**Creating Precedent**

Sometime around the turn of 1970/1, a pre-eminent actuarial scientist, Bernard Benjamin, made a visit to the Computer Control Laboratory at the University of Cambridge, where he encountered (by chance, but not surprisingly) a control engineer, Les Balzer, a PhD student at the time. It was a significant moment in what Benjamin later referred to as his “Personal Journey” (Benjamin, 1982; p 285). The subsequent collaboration between Benjamin and Balzer bore fruit in just two papers, the first published in 1980 (Balzer and Benjamin, 1980), the second in 1982, which comprised a major technical part (Balzer, 1982), prefaced by Benjamin’s account of his personal journey (Benjamin, 1982).

The object of Balzer and Benjamin’s analysis was the problem of what actuaries call “delays”, and what, we now appreciate, control engineers call pure dead time in the feedback of

\(^{18}\) Indeed, this was a line of reasoning presented in 1979, well before the first complete exposition of the theory of plural rationality in *Cultural Theory* (Thompson et al, 1990).
information about an insurer’s (accumulated) surplus (a $y$) to the setting of a premium rate for new policies (a $u$). A claim goes into the pipeline and some time later out pops a chunk of surplus (or deficit); and the effects of this transportation lag are duly translated into determining the product’s premium price. In this the timing of the Benjamin-Balzer encounter is significant. At the turn of the 1960s/70s digital computing was rising to overwhelming predominance in the domain of system simulation in general, and control studies in particular. Indeed, at the time of Benjamin’s visit, the Cambridge Computer Control Laboratory had not only analog and digital computers but even a (presumably short-lived) hybrid variety of analog-digital computer. Digital computing made discrete-time, difference-equation representations of a system’s dynamic behaviour so much more “natural”. And this is crucially important here, because such models accommodate so much better the analysis of problems with pure dead time than their companion continuous-time, differential-equation representations. Not having to solve differential equations on the computer would have been a further distinct advantage of difference equations in 1970/1.

More specifically, Benjamin had come to be pre-occupied (since at least 1966) with the problem of how to remedy the stark inadequacy of what we would describe as the “open-loop” simulation of future actuarial experience. He related it thus (Benjamin, 1982; p 285):

To carry out lots of simulations of future experience without changing the valuation in each simulation according to its own development will not illustrate our control of surplus in any useful way at all — to ourselves or anyone else.

The open-loop character of the simulation is conveyed in the sense that, as the simulation proceeds from the present into the future, passing from one future year ($t +1$) to the next ($t +2$) across the forecasting horizon, no information about a firm’s output financial surplus at any future point (($t +1$), ($t +2$), and so on) is employed to determine the input premium at any such future (simulated) time. The premium put into the model has been determined right here and now — in the (simulated) present of $t$ — for all time into the future, regardless of the trajectory of the simulated surplus output from the model. The loop to feed back something about the output side of the system to the specification of something about the input side of the system remains open, disconnected. Accordingly, Benjamin concludes this (Benjamin, 1982; p 285):

Without inserting that decision process into the simulations themselves, there is little point in simulating.

Without closing the loop, in other words — without creating and installing the feedback decision rule, from knowledge of something about the value of the accumulated surplus (a $y$) to a value to be specified for the premium to be charged (a $u$) — the simulation exercise serves little purpose.

Closed-loop simulation, on the other hand, would function across time ($t$) as though it had an (engineering) feedback controller: keeping the accumulated surplus at a level to our liking,\textsuperscript{19} in the face of all manner and sequences of incoming, disturbing, disruptive claims ($d$), by continually adjusting the premium each year ($u$) as a function of current knowledge of the

\textsuperscript{19} Plural rationality and all the foregoing discussion (in Section 3) of plural aspirations for the desired behaviour of a system obliges us to ask “Exactly whose would be this ‘our liking’, then?”
accumulating surplus \((y)\). But in 1970/1 Benjamin had yet to arrive at that insight. His observations, as far as we can discern, appear to relate to a paper he had written back in 1966.

Over the subsequent decade of the 1970s Benjamin was training Balzer’s command of control theory onto the problem best described by the title of their joint paper (Balzer and Benjamin, 1980): “Dynamic Response of Insurance Systems with Delayed Profit/Loss-Sharing Feedback to Isolated Unpredicted Claims”. In its Summary they report the following, duly annotated (here now) according to the protocol of this report’s notation (Balzer and Benjamin, 1980; p 513):

A mathematical model of the dynamic behaviour of an insurance system with delayed profit/loss sharing feedback is developed. The model is then subjected to a disturbance input \([d]\) consisting of an isolated group of unpredicted claims and the dynamic responses of cash flow and accumulated cash flow \([y]\) determined. Increasing delays [dead time] are seen to lead first to undesirable oscillatory responses and eventually to instability [in \(y\)], where the responses become unbounded. Such behaviour is noted to be independent of the type of business and to be a property of the feedback mechanism and not related to the type of disturbance input \([d]\).

Beyond oscillatory behaviour their analysis had encountered instability in the system’s response, hence the need to stabilise — through the design of a controller (the decision rule) — that which is inherently oscillatory or unstable in that dynamic response, because of the pure dead time (delay) in the feedback (Balzer, 1982). And oscillations, of course, are the stuff of which cycles are made, notably insurance cycles herein, ergo the discussion of Section 4.2 below.

For present purposes, however, it is in Benjamin (1982) where this problem is most clearly expressed. It was at the core of his quest (and he himself recognised it should have been included in Balzer and Benjamin (1980)). Thus, premium in year \(t\) is calculated according to the simple arithmetic of:

\[
\text{[a base premium]} - [(a \text{ percentage of)} \text{ accumulated surplus at year } t-1]
\]

in which \(l\) is the pure dead time (or \(\Delta t\), as denoted alternatively above). There is no oscillation in the premium as the system (the firm) responds to those “isolated unpredicted claims” when \(l\) is one year, but there is when \(l = 2\) or 3 or more.\(^{20}\) Prior to his collaboration with Balzer,

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\(^{20}\) There is a subtle but important technical note to be made here. In a discrete-time representation of the unsteady-state, dynamic behaviour of a system, something gets lost in translation from the corresponding continuous-time, differential-equation representation. In the latter — in the absence of dead time — it is formally possible for a change in the incoming disturbance \(d\) to be apparent “immediately” in the system’s output response \(y\) after an infinitesimally small elapse of time. In the corresponding discrete-time form (and technically, of course, in any numerical solution of the differential equation), such instantaneous translation of the change in \(d\) to a perceptible change in \(y\) is not possible. In the case of insurance systems, then, where it is natural to think in terms of discrete decision points \(t-1\), \(t\), and \(t+1\) separated by years, quarters, months, weeks, or days, any sudden abrupt change in \(d\) at time point \(t\) would not be perceived in the firm’s output performance response \(y\) until \(t+1\), which might well be a year hence, not a nano-second hence. When, therefore, from the Balzer and Benjamin (1980) study onwards, dead time \(l\) (our \(\Delta t\)) is set to 1, this may \textit{technically} be associated with a system in which changes in \(d\) may actually be translated immediately, in but an instant, into changes in \(y\). We have thus the subtle but important difference between control theory’s “delay” \emph{vis à vis} “dead time”. Delay means technically an immediately perceptible change in the system’s output \(y\), with then a significant delay in \(y\) evolving towards (and eventually reaching) a new steady state following, in particular, an abrupt step change in \(d\). Dead time means that intrinsically no change in \(y\) may be perceived until the span of time \(\Delta t\) has passed. Only thereafter may the subsequent changes in \(y\) exhibit the delayed response to the input step change as it subsequently evolves towards its new equilibrium value.
Benjamin had found such a qualitative change in dynamic behaviour discomforting. He could appreciate how the algebra led to it — a sinusoidal function appears in the analytical solution to the difference-equation model — but he could not clarify the puzzle of why. What Les Balzer diagnosed, therefore, was the fact that Benjamin had been using a so-called proportional (P) feedback controller for setting the firm’s premium. Furthermore, observed Balzer, there are ways and means in control theory for correcting for this inadequacy of P control, by using, in addition, some elements of what are called integral (I) and derivative (D) control action.\textsuperscript{21}

But all that was not known to Benjamin in 1970, when his colleague, Henry Seal, had, as Benjamin tells it (Benjamin, 1982; p 286):

... set up a very simple model of the total annual claims of a motor insurer. He then set up several ‘rules’ for setting the premium rates based on recent experience. All of them were intuitively reasonable — like taking the average of previous years (in the days before inflation). Some of the rules had been suggested by other actuaries. The simulated insurance companies went broke.

This, to me, was the first actuarial paper which explored the decision procedure itself, i.e., the procedure which used the experience to determine and change the control variable.

However, there was one aspect of the data which ... was giving me difficulties even in the most simplified model of my problem. It was the delay in the information which was inherent in the situation. As Brian Hay puts it cogently, “it is all very well trying to forecast the next few years, but we don’t even know what has happened in the last few years; we’re still having to forecast that”.

These — dead time, feedback, the ruin of simulated firms — were the essence of the problem that the novelty of control theory, suitably transcribed across to actuarial science, was to solve. Yet as Benjamin recalled of his personal journey across the 1970s, in a wonderfully “old-school”, chiding kind of way (Benjamin, 1982; p 288):

Economists have entered the field, describing economic systems with control theory methods and concepts, mostly using matrix methods. Much of this work appears to be enjoyable mathematics which is difficult to follow.

How telling for us too. For it is not the \( z \) transforms, the block diagram analyses, the algebra, the applied mathematics, and so on that we now need from control theory, but the concepts and principles standing beneath them.

\textit{From Classical to Modern}

Benjamin and Balzer had established an important precedent. Yet a casual google search on the Balzer and Benjamin paper of 1980 reveals it has been cited by only a few tens of other authors in the past four decades. Two of the later articles are those of Zimbidis and Haberman (2001) and Yang \textit{et al} (2016), whose contributions we now review.

Taking the former, we may begin by quoting their broader definition of the pricing problem (Zimbidis and Haberman, 2001; p 264):

\begin{footnotes}{21} The result — PID control — is a fundamental principle of classical control system design. And how much of each — of P, of I, of D — to design into the controller (decision rule) would come under the choices for those parameters (those \( \alpha \)) embedded in the model as \( k \).\end{footnotes}
Consider a portfolio of individual non-life insurance policies. Under normal circumstances, the insurer calculates the required annual premium in order to cover the expected claims plus the respective administration expenses and the desired profit margin.

In terms of outcomes, there may be a year with unexpected high (low) total claims in which the insurer realizes an extra loss (profit) which consequently reduces (increases) his own initial surplus. Then, the insurer may decide to increase (reduce) the premium in order to recover (refund) some of the loss (profit) from (to) the policyholders. But how much should the insurer recover (refund)?

Their premium-setting decision rule has also become somewhat more elaborate than that of the basic arithmetic of Benjamin’s original skeletal form. Thus premium in year \( t \) is set as the difference of these two expressions (Zimbidis and Haberman, 2001):

\[
\text{claims estimate at time } t \text{ (as a function of past claims going back to year } t-l) \quad \text{ - } \quad [(\text{a percentage of) accumulated surplus at year } t-l]
\]

Both terms in the feedback loop of the insurer’s management team are now subject to dead time \((l)\). In fact, the estimator of the claims at \( t \) in the first term is assumed to be a weighted average of the recently available experience of claims, such that the current estimate of the current year’s claims might call upon claims data going yet further back in time than year \( t-l \), i.e., beyond the dead time \((\Delta t)\) in the system. In line with Balzer (1982) and using the same approach (of the “root locus” method), Zimbidis and Haberman analyse the stability of the above relationship (or model), for when \( l = 1 \) and \( l > 1 \) year. Hence they derive bounds on the feedback factor, the proportional \((P)\) control parameter \( k \), within which bounds, any choice of value for this “percentage” \( k \) in the second term of the pricing relationship will not induce instability. Subject to these bounds, Zimbidis and Haberman (2001) proceed to optimise the feedback controller so as to achieve the swiftest possible post-disturbance recovery of the system.\(^{22}\)

We may conclude then that Zimbidis and Haberman (2001) present something of a generalisation of the earlier results of Balzer and Benjamin, without calling into service any significantly more advanced or more modern (post-1970) control theory.

Yang et al (2016), however, do just that. To appreciate how this is so, let us first quote at length from their paper, with emphasis added (in bold italics) to highlight themes of special significance for the subsequent discussion and development of our principal topic of Rational Adaptability (Yang et al, 2016; pp 3-4):

In the insurance industry, the interest in time-varying parameter models has increased over recent decades. The Solvency II framework and the development of some national regulations have increased the interest in the stability and robustness of the models used to describe the behaviour of insurers. Examples of this are the studies of Pantelous and Papageorgiou (2013), and Pantelous and Yang (2014, 2015), which apply recent claim experiences and a feedback mechanism based on the surplus value to control the premium level. All of these models assume only one standard regime for the premium-reserve (P-R) system. However, in financial economics it has been indicated that statistical relationships between variables in many macroeconomic/finance models may be inconsistent. Thus, we can model, and even possibly predict, such discontinuity in many different ways, because it

\(^{22}\) In passing, we note that for certain (deterministic) patterns of incoming claims disturbances \((d)\) the otherwise unstable performance of the insurer can be stabilised by adding an element of integral \((I)\) action into the decision rule. This too is in line with the findings of Balzer (1982).
may contain dramatic changes in the system’s behaviour. Such discontinuity is mostly
associated with events such as financial or economic crises, or with significant changes in
government policies. In practice, for an insurance company and its stakeholders different
strategies should be implemented in different economic environments. Therefore, an
"ideal" model of the P-R process should be able to take into account this significant factor.
One possible technique, which is widely applied in financial economics, is given by so-called
regime switching models. In these models, the studied processes are assumed to have
several “regimes”, with their own regime specific parameters and rules for regime
switching.

In studies relating to quantitative finance, regime switching models attempt to capture the
long-term instabilities (or structural changes) in the various variables involved in a model.
Some well-motivated, and popular examples are bull and bear regimes alternating in
financial markets and their economic impact, the well-known phenomenon that exchange
rates tend to alternate over protracted periods of depreciation and appreciation, and the
fact that monetary policy can suddenly change on account of downward and upward
swings in the economy.

Several are the control theoretic innovations in their subsequent “enjoyable” if “difficult”
mathematical analyses (as Benjamin might have said of them). Indeed, given such difficulty,
most of the innovations have been put aside in order to leave ourselves free to concentrate
on why “time-varying parameter”, “structural changes”. “regime switching”, and the other
words and phrases have been highlighted.\(^\text{23}\)

The pure dead time in the system’s model (our \(l\) or \(\Delta t\)) is treated by Yang et al. (2016) as a
parameter (one of the \(a\)) and — crucially — deemed to be time-varying. It may assume one of
two values (of 1 or 3 weeks), between which it is simulated to switch back and forth over time.
In effect, each value of the dead time is associated with one or the other of two prevailing
economic regimes in the supra-system surrounding the given insurance firm, e.g., of bull
market, bear market, currency depreciation, currency appreciation, or whatever. “We assume”,
these authors say, “that the insurer will alter [her/his] operating regime under the influence of
some key [external] economic and market factors that are not constant” (Yang et al., 2016; p 20).
According to their particular illustrative choices, the regime in which the dead time is 3 is
described as the more volatile of the two. It has (a) markedly higher interest rates on assets
(reserves), (b) a somewhat higher base rate of surplus return to policy-holders, and (c) a
differently parameterised proportional (P) feedback controller for the reserve process. All
three of these factors — i.e., the other parameters \(a\) in the model besides the dead time —
determine the dynamics of the reserve process and the setting of the premium rate. Greater
uncertainties are assigned to this threesome of parameters during the more volatile regime,
relative to their assigned uncertainties for the less volatile regime (in which the dead time is
1).

Collectively, therefore, the time-varying dead-time parameter and the regime-dependent, ergo
time-varying values for the model’s other three parameters define the system being described
as one that undergoes structural change (to which we shall return, as we have said, in Section
4.5 below). But it is structural change of a rather strange kind, in the sense that whatever is
changing at a deeper level, inside the basic mechanics of the system’s or, in this instance, the
supra-system’s behaviour, is not evolving towards something novel, never previously

\(^{23}\text{For completeness we note the work of Kreuser and Sornette (2019), which, while it pursues a different line of
mathematical reasoning, i.e., not one from control theory, seems to echo ideas of “jump processes” and “regime
switching”.}\)
witnessed. Rather it is shifting back and forth between what is quite familiar and conventional: the same old same old; regime one or regime two.

Yang et al (2016) test their controller for its success in stabilising fluctuations and instability in the company's financial reserves. To do so, they compose a disturbance of the system (a $d$ indeed), which technically would be described as an aperiodic binary square-wave sequence of crisp floor-to-ceiling ups and downs. In actuarial terms, these are switches in the relatively longer-term, more macroscopic, more strategically significant economic-financial status of the outer supra-system, i.e., the environment enfolding the cut-out system of the individual insurer. They may be switches from a bull market to a bear market, back and forth, and back and forth — but too abrupt to be exactly pendulum-like (as in “Beyond Boom and Bust”; Thompson, 2008b).

For us here, these regime switches evoke a sense of dramatically fast, if not extreme, versions of changes in our risk-coping seasons. In fact, we may designate this switching disturbance of Yang et al as operating in that now almost forgotten macro time $T$, which was introduced back in the introductory remarks of Section 2 of this report, but hardly since mentioned (which is not insignificant, because it was not needed across the entirety of Section 3). The $d(T)$ are symbolic of the insurer's risk environment and of qualitative changes in the nature of that risk.

Continuing with the more technical details, two test sequences of $d(T)$ are used, one with relatively fast switches between regimes (short-duration seasons), the other relatively slow switches (longer-duration seasons). And as we might expect for a binary sequence, a two-regime (as opposed to a three- or four-season) Markov jump process is used to synthesise the two sequences of disturbances $d(T)$: the former with a transition probability matrix in which the regime with a dead time of 1 decision period (in micro time $t$, that would be) is more likely to stay the same than is the second regime (associated with a dead time of 3).

But what does all this have to do with the dead time in the claims estimator-process with which this brief journey through control theory began? Taking stock, and looking back to the seminal studies of Benjamin and Balzer, as well as those of Zimbidis and Haberman, whence have we come?

First, there are now two entities that are being considered by Yang et al (2016) as disturbances $d$ of the system (the firm): the regime-switching sequence, which is associated with the (unmodelled) dynamics of the supra-system surrounding the firm and operates in macro time $T$; and, as before, the claims sequence coming into the firm, which operates in micro time $t$.

Second, the original (1970s) problem of the dead time ($l$), in what came to be recognised as the proportional (P) feedback control loop (from output accumulated surplus to input premium-setting), is still there. $l$ still appears in the premium-setting arithmetic, in both the claims estimator part and the reserve refunding part, as was the case for the analysis of Zimbidis and Haberman (2001) (but not for the collaboration between Benjamin and Balzer).

Now, of course, dead time ($l$) is also present as the defining attribute of the regime-switching disturbance, whose changes march along with the switches of regime (season) in macro time $T$. It has become an $l(T)$ (or a $\Delta l(T)$): a time-varying dead time, albeit one which jumps about in a very particular way. Moreover, and still as before, the switches in $l(T)$ reach into the heart
of the very same (but now time-varying) dead time in both the reserving process and the premium-setting prescription. Absent from Yang et al (2016), however, is any kind of probing of how to design a good (Proportional + Integral) premium-setting controller with the conventional “spike” (impulse or pulse), “step”, and “ramp” test disturbances — the micro time $d(t)$, that is — evaluated in Zimbidis and Haberman (2001).

Third, and likewise for comparison and contrast, instead of seeking to increase the speed of post-disturbance recovery in response to claims disturbances (a previous object of study), the controllers in Yang et al (2016) are optimised so as to minimise the maximum loss of reserves post-disturbance. In addition, this other kind of design of feedback controller — the company’s decision rule for stabilising its reserves — is switched from one formulation (one choice of $k$) to another when the (supra-system) regime shifts from one to the other. It does so “instantaneously”, with no delay (dead time) whatsoever, i.e., it achieves theoretically perfect Rational Adaptability (as we shall see, in Section 4.4).

Fourth, the pedantic control theorist would insist that there are two controllers (not just the one) acting on the reserve process in the Yang et al (2016) study.24 Moreover, the two bear a hierarchical relationship one to the other. Thus, knowing the incoming switching sequence $d(T)$, this observed information is fed forward (instantaneously and as though perfectly known) to prompt the throwing of a (control) switch in the insurance company: the current formulation for the reserve controller (the second controller) is swapped out for the other. Knowledge of $d(T)$ is used to change the therefore time-varying $k(T)$ of the robust, maximum-loss-minimizing reserving controller. This first control loop, from $d(T)$ to $k(T)$, would be called a feedforward controller. What is more, this feedforward controller dictates the form of the second, feedback controller, which, conversely, is informed by what is happening to the firm’s output performance, $y(t)$. The upper-level feedforward controller tells the lower-level controller what to do — and expects it to get on and do what it has been told. Whereas the lower-level feedback controller is jiggling about frenetically with its actions in micro decision time $t$, the feedforward controller conducts its affairs in a more sedate manner, occasionally changing its mind from macro-time to macro-time with regard to what is to be done.

Fifth, and just for good measure, what is being designed and exercised in the Yang et al study is a multivariable controller. But it does not acquire this label as a result of the pair of feedforward and feedback control loops just described. All of the above, in this Section 4 so far, has been referred to but one insurer or one line of insurance. In contrast, Yang et al (2016) address the challenge of an insurer with multiple lines of business, each of whose respective reserves may be stabilised in the manner summarised above. Moreover, they account for the fact that the behaviours of the several lines of business and their respective reserves may be interacting with one another, hence the overall multivariable controller as a whole should be designed to cater for this. Notably, actions taken to stabilize one reserve should not destabilize those of another. To have entered thus into the domain of multivariable control system synthesis is to have crossed the conceptual (perhaps arbitrary) divide separating

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24 There may be three control loops, which would not be surprising, given the previous controllers studied and designed by Balzer (1982) and Zimbidis and Haberman (2001) for the “control” of the premium-price setting by feeding back information about the accumulated surplus (duly manipulated by the application of some Proportional (P) plus Integral (I) action). Yang et al are somewhat vague about this, however. Although they do provide this rather helpful visualization (Yang et al, 2016; p 9): “Both the premium and reserve processes have a linear relationship with the original claims process. The claims process is a driving force in the system, and the control equation [control loop] determines how the total ‘energy’ of the claims process is channelled via the system to the premium and the reserve, respectively.”
classical from modern control theory. In particular, the multivariable model of the insurer’s
dynamic behaviour in Yang et al is cast as a so-called state-space representation.25

4.2 Dead Time, Oscillations, Cycles, Regime Shifts, and Seasons

There is, we submit, more than just a prima facie case for mobilizing the principles and
concepts of control theory in designing ways of coping with cyclical behaviour in insurance
and financial systems. That was where it started, with Benjamin’s concern for dead time in the
system, its capacity to induce oscillations and instability (hence ruin), and Balzer’s revelation
to Benjamin of the capacity of classical control theory for coping — up to a point — with
oscillatory behaviour. From that beginning, Section 4.1 has ended with modern control
theory’s capacity to begin dealing with cyclical, seasonal behaviour in the more macroscopic,
strategic, longer term.

In addition, a system whose behaviour is not represented by a model with time $t$ as the all-
important independent variable is anathema to control theory and control engineering. Yet
even as late as 1980, when Balzer and Benjamin published their first paper, in the Journal of
the Institute of Actuaries, they felt it necessary to begin with a statement of their “modelling
philosophy”, as if to suggest such was unusual. They say (Balzer and Benjamin, 1980; p 516):

The starting point of any control investigation is the development of a mathematical
model of the dynamic system to be studied. [with emphasis added]

Control engineering is about taking the dynamic behaviour of a system as is and re-
engineering that dynamic behaviour so that it is more to “our” liking. Once, of course, no-one —
especially not a student of control engineering (MBB) — would have wrapped the word “our”
in quotation marks, thus to raise a question about it. How times change. For just exactly whose
“our” is it, now that we are so keenly aware of the theory of plural rationality from social
anthropology? In fact, our report (heaven forbid) is heading towards a marriage of control
theory and social anthropology in the service of addressing model risk and Rational
Adaptability in ERM. A kind of “courtship” between the two (anthropology and control, that is)
has long been in place, ever since publication of the book Rubbish Theory (Thompson, 1979,
2017), as we shall see towards the end of the next subsection (4.3).

Accordingly, we here set about linking the insights from the foregoing account of some control
conjectures (Section 4.1) with what has been called the anthropological hypothesis in
actuarial science, with the exposition of which most of Section 3 is occupied.

25 The state of the system, often denoted $x$ in the lexicon of control theory, lies between disturbance $d$ and response
$y$ of the system. As $x(t)$ it represents the status of the system at time $t$. Together with the parameters $a$, $x$ is a part of
the “internal” description of the system’s behaviour, whereas $d$ and $y$ belong to its “external” description. In the
model of the system’s behaviour, $x$ and $a$ describe the mechanics of how the impact of incoming disturbance $d$ (and
control action $u$, for that matter) is translated into the outgoing response $y$. In practical terms, $x$ is commonly the
hypothetical noise-free correspondent of the observed $y$. However, it is easy to conceive of a model of a system in
which the vast majority of the states $x$ are unobservable, with no corresponding $y$’s. We simply do not have the
monitoring capacity to observe everything important about the state of a system.
Creating a Market Cycle

There has been much discussion about the possible causes of the market cycle in the Property & Casualty insurance industry but little consensus. This paper will offer a simplified behavioral model, showing how a market cycle can be created assuming naive rules for reserving and pricing business. The model can be interpreted as a linear difference equation, which naturally gives rise to a cyclical pattern. This model is shown to be consistent with published financial results in several ways, and offers a testable leading indicator of future market turns.

Thus begins a 2010 Casualty Actuarial Society (CAS) Working Paper (Clark, 2010). No mention is made of the analysis of Balzer and Benjamin (1980), but the approach and the end-point are identical. In a nutshell, here is the technical-mathematical logic.

Discrete-time, difference-equation representations are used for the premium-pricing and reserving processes in an insurer, although the behaviours therein described are said to mimic the basic rules of behaviour assigned to agents in the agent-based model of Mango and Venter (2007). In these processes the claims estimator is chosen to be a function of a Bornhuetter-Ferguson distribution, going back several decision-steps in time, hence the presence of delay and dead time. This, Clark argues, is tantamount to a "speed to recognise" the true ultimate loss to the insurer of the claims coming into it. This "lag" (our dead time) in the reserving process, he continues, is not recognised by the industry; and leads to what others have called the "industry delusional factor". With suitable such assumptions in place, Clark's deterministic difference-equation model has an analytical solution (as did that of Balzer and Benjamin, 1980). In what is referred to as the most basic case of the model, when the Bornhuetter-Ferguson distribution has but one term in it, introducing thereby a delay-cum -dead time of one decision-period, the analytical solution is a trigonometric formula in which a cosine function is present. Nothing stochastic is needed for the model of the system to exhibit oscillatory behaviour: that qualitative change in behaviour, driven by the algebra of the model, that had so puzzled Benjamin back in the 1970s.

As his punch-line, Clark concludes the following (Clark, 2010; p 15): "reserving and pricing that ignore the cycle" (in practice, not merely in the model) "are sufficient to produce a cycle". Cycles in the insurance market, we might conclude, are inevitable (and not necessarily undesirable) and we overlook the role of that most troublesome of attributes, dead time, at our peril. Something in the workings of the system is such that, when something is done unto the system — some sort of input perturbation impinges upon it — nothing is sensed to have resulted from that perturbation. Accordingly, and typically in manipulated systems, yet more of the same is done unto the system. When eventually the system does respond, what happens is perceived as excessive, hence the exact opposite of what was first done unto the system is done to it ... and so on, back and forth, up and down. This is what Benjamin and Balzer encountered in the workings of actuarial science; it is what some of us may have

\[26\] And the vocabulary of the Working Paper — one word in fact, “recursive” — is unexpected. “Recursive”, which seems to be more redolent of control theory than of statistics or actuarial science, appears in the general form of recursive algorithms for the (real-time) estimation of model states (x) and parameters (α). With the advent of modern control theory and those guided missiles, control engineering had an urgent need to work out in real-time exactly what would be the most up-to-date model of the system’s dynamic behaviour in order to implement up-to-the-minute guiding control action. It should be no surprise then that the 1984 book Recursive Estimation and Time-Series Analysis should have been authored by Peter C Young, a control engineer (and co-author of the Regionalised Sensitivity Analysis at the heart of Section 3.4).
experienced in the shower, freezing and scalding by turns — at least on the first occasion, when the user is ignorant of any dead time in the system.

But there are at least three other ways for oscillations to be induced.

**Excessive Feedback Control**

When a system is disturbed, and disturbed away from some desired operating point in respect of its output $y$ — a nice, healthy, steady accumulated surplus, for instance — how quickly it can be returned to what is desired can be very important, especially when the system has a lot "inertia" associated with its dynamic behaviour. Control theory has ways and means of selecting the ingredients of the P, the I, and/or the D components of the feedback controller (those design parameters denoted previously as $k$) in order to accelerate the system’s recovery. The only trouble is that, as the $k$ (of simple P control) is pushed upwards, quick recovery morphs into transient overshoot, and then overshoot with subsequent undershoot, or worse, overshoot-undershoot-overshoot, and so on — oscillation(s), in short, if not instability.

In the late 1980s, as traders increasingly benefited from real-time, automated rules for buying and selling stocks, a well known control theorist observed (on some reported instability in the market) that the "gain" (the $k$) in the system had been turned up too high. What he meant was this. In response to changes in the values of the various stocks (system outputs $y$), too much of the same buying or selling of stocks (system inputs $u$) was occurring. In effect, we could say that the gathering herd — all locking on to the same "knee-jerk reaction" — was, in effect, inflating the $k$ in the feedback loop between $y$ and $u$.

**Too Little Damping**

Irrespective of any imperfection in the decision loop, the system may have too little (natural) damping in its mechanics. The classical analogy is indeed something like a mass tethered by springs to immovable anchoring points, which mass may be disturbed. The mass will return to stasis at its equilibrium point, but only after more or less oscillation, which behaviour will be dependent on the strengths of the springs.

Those analysing long time-series of national GDP data have used exactly this analogy to explain their interest in, and approach to, searching for signs of the weakening, over the long term, of what they call the "restorative forces" in an economy (Diks et al, 2015; Rye and Jackson, 2016). Which is to say, given a (hypothetical) shock to the UK economy in 1959, that economy would have recovered its prior upward trend in GDP after just one short season of shallow bust-recession. Given the identical (hypothetical) shock in 2019 recovery might take one or two long seasons of deep burst-recession with a short-lived season of but weak, partial recovery in between.

Masses, springs, restorative forces and, of course, the abstract, dry, inanimate trigonometric cosine or sine function in the analytical solution to a model so simplified as to submit to being solved analytically are, of course, informative in their own ways — but where is the human element in all of this?

It is time indeed to examine what causes the pig cycle in the system of ceremonial gift-giving in New Guinea.
4.3 Social Dynamics: A Strenuous Exercise in Cross-disciplinary Systems Thinking

To recall, we are currently en route from a set of control conjectures (in Section 4.1) to their conjoining with a social anthropological hypothesis (expounded in Section 3), in order to enhance our understanding of the insurance cycle, hence to cope with risk in the presence of this cycle. Control, therefore, is here about to meet anthropology in the theoretical framing of economics and — joking quite apart — the observed empirical context of ceremonial gift-giving among communities in the highlands of New Guinea. In short, what follows is an interpretation by a control engineer (MBB) of what the social anthropologist (MT) wrote some four decades ago in his first book, *Rubbish Theory* (Thompson, 1979, 2017).27 By the end of this subsection we shall be able to look forward to what will then be said of Rational Adaptation.

The Observed Cyclical Phenomenon

This is the observed phenomenon (without going into its extensive detail). The total pig population in the social chain of communities between Minyip and Talembais in New Guinea is subject to a cycle with a period of roughly four years (Thompson, 2017; Figure 31, p 194). This pig cycle is argued to be driven by a “credit cycle”, whose turning points anticipate slightly the turning points in the pig cycle (Thompson, 2017; Figure 32, p 196). To understand the causes of the pig cycle, the effect of the credit cycle obliges a further translation into the distinction between “disposable pigs” and “breeding pigs”, the populations of both of which likewise cycle with time, the latter leading the former (Thompson, 2017; Figure 33, p 200). In all three sketches of the dynamics of the system, the declining phase of any of the cycles occurs more swiftly, if not calamitously so, than the growth phase. As generally observed in all such socio-economic cycles, the season of Bust is shorter than the combined seasons of Moderate-Boom.

The Framing of Economic Theory: A Proportionality Constant in Keynes’ Fundamental Psychological Law of Economics

Though not quite the same as the celebrated trade cycle in Economics, the pig cycle is nonetheless born of exchanges of objects among people in various geographically separated communities. Trade cycles, for their part, were first noted and formally addressed by economists in 1878, although not adequately theorised about and explained until the work of

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27 The book is a search for a theory of value in economics. It is motivated by this essential question: How can it be that objects we call “consumables”, with a value that declines with time, may become “durables” with a value that increases with time? Conceive, for example, of a car or a piece of furniture that endures and survives to become a vintage object or prized antique. How do these changes occur? The answer is: the transfer is only possible if one inserts a category of objects referred to as rubbish, with no value and in a state of timeless limbo. Hence the book’s title, *Rubbish Theory*. The vast majority of the material of the present control theoretic interpretation of the pig cycle is drawn from Chapter 9 of *Rubbish Theory*, on the “The Geometry of Confidence” (Thompson, 2017; pp 186-215). In the Foreword to the second edition (2017) of the book, Joshua Reno refers to this and the later chapters of the book as having been regarded (over the decades) as “excessive or unnecessary” (Thompson, 2017; p xi). For his part, Reno considers them thus: “[t]hese rubbed sections ... cry out for further discussion and dissection” (Thompson, 2017; p xi). This is what indeed one of these chapters is here getting. Last, but not least, it is accordingly far from insignificant that not one word in the texts of the book’s ten chapters in the 2017 edition of *Rubbish Theory* has been changed since the first edition of 1979.

Many have argued that oscillations in trade are the result of a society’s pursuit of its cultural values until constraints are encountered, such as natural resource limitations. One model, however — the Hansen-Samuelson model — shows how economic fluctuations may be obtained in the complete absence of constraints, solely as a function of “the interaction of those two Keynesian concepts: the Multiplier and the Accelerator” (Thompson, 2017; p 197). Within the latter is embedded Keynes’s fundamental psychological law:

“That men are disposed as a rule and on the average to increase their consumption as their income increases but not by as much as the increase in their income.”

In other words, Keynes obliged himself to take *individual motivation* into economic account “but conveniently and, alas, erroneously was able to treat it as a constant” (Thompson, 2017; p 198, with emphasis added). Keynes assumed it would be sufficient for his purposes for the proportion (an $a$) of marginal increase in income spent on a marginal increase in consumption to be held constant with time.

### Economics and the Constant Marginal Propensity to Consume: First Candidate Explanation

Hansen and Samuelson, while restricting their attention to a buffer-less economy, did not question the simplified assumption about the marginal propensity to consume. Thus, as expressed in *Rubbish Theory* for the purposes of a first candidate explanation of the pig cycle in New Guinea, Thompson continues (Thompson, 2017; p 198):

> The Hansen-Samuelson model of the trade cycle incorporates this very simple feedback mechanism [of trying to maintain a desired productive economic output ($y$) by continually adjusting productive plant capacity (through a $u$)] — inevitably time-lagged information concerning levels of demand — and gives rise to cycles even in the absence of buffers. These cycles will, in general, be generative: either damped (settling down and dying away) or anti-damped (getting worse and worse) and only at one specific set of parameters will they be of constant amplitude.

This now is very much control speak, with dead time re-surfacing in the phrase “time-lagged”. Indeed, Thompson reaches for an everyday mechanical metaphor to illustrate how this works in the most familiar of terms possible. It is a room-heating system, albeit not a bathroom shower. The metaphor — the logical model of the heating system — should be capable of being massaged until the pair of curves of variations in populations of disposable pigs and breeding pigs over time is fitted. It is just a matter of “playing around with the parameters” in the Hansen-Samuelson model, argues Thompson (Thompson, 2017; p 199).

But the physical mechanics of showers and home-heating systems are simply not transferrable to the biology and ecology of pigs and the sociology of their husbandry in New Guinea. In particular, they cannot account for the almost snap decision of the pig breeder to convert a breeding pig into a disposable pig (by slaughtering it), which decision is driven by the *confidence* (hence the title of the chapter) the individual pig breeder has in the future.
A (much) more refined and subtle social-anthropological model is required if the pig cycle is to be reasonably well explained. Counter-intuitively, perhaps, it is one that will bring us back to the notion of models with time-varying parameters. What is more, it has to do with how power and belief systems are manifest in the specific culture of the communities along the ceremonial gift-exchange route between Minyip and Talembais.

Second Candidate Solution: Social Anthropology, Ideologies, Power, Persuasion, and Reneging

Credit, in these particular communities in New Guinea, is extended to individual pig breeders as a function of two competing principles or ideologies, i.e., for us, ways of seeing the world and acting in it. Again, without going into detail, one ideology is that of the so-called “big man”. It is the “big man” in the community who extends the credit to the pig breeders, to assist them in breeding more pigs. The big man is in single-minded pursuit of “pig power” (Thompson, 2017; p 202). Re-enter then the theory of plural rationality of Section 3 above — not that that was how this was seen in 1979, just over a decade prior to the publication of Cultural Theory (Thompson et al, 1990).

The big man’s ideology, which he surely seeks to sell to his followers, is that of what we should call herein the maximizing, individualistic I-type rationality. The big man is, and all his followers should be, rational economic men — rational utility maximisers. The world of the big man, and that of his followers, is one of certainty, of confidence in the future, of Rumsfeldian known knowns. In the closed hegemony of the big man ideology, upswings in the pig cycle become almost inevitable.

The co-existing, but partially competing, second ideology is described as one of a cultural “segmentary lineage system”. To this attaches, in short, the hierarchical H-type way of seeing the world: that of “islands of certainty set in the turbulent sea of unpredictability” (Thompson, 2017; p 204); a world of known unknowns, we might suggest; a world in which there can be some diffidence about the future.

Crucially, credit relationships may be extended by the big man in ways that are validated by the segmented lineage protocol and in ways that are not. Avarice and aggrandisement drive the big man to abuse the protocol. The ratio of credit relationships extended in the one way versus the other becomes the “controlling” factor in Rubbish Theory’s second candidate explanation of the pig cycle. In effect, it becomes therein (in Rubbish Theory, that is), a parameter of a catastrophe theory model of the dynamics, in particular, of the sudden discontinuity of downswings in the cycle — of qualitative, structural changes in the dynamic behaviour of a system. But making an appeal to catastrophe theory is not how we intend

28 The pig breeder actually has what modern control theory calls a predictive control problem, but its solution may still be very much a feedback, as opposed to a feedforward, controller. In this instance, the status of the system’s output (regarding the population of pigs) some f decision-periods into the future must be predicted, as ŷ(t + f). This may be compared with what is wanted of that output f steps ahead, and the resulting information fed back to the breeding-slaughtering decision to be made right here and now, i.e., u(t).

29 At the very end of the chapter, the following reflection is offered (Thompson, 2017; p 215). “In trying to assess what, if anything, the significance of all this is (apart from the sheer delight involved in trying to solve difficult problems) it occurs to me that though this catastrophe theory approach succeeds where even the Hansen-Samuelson model fails, it is nevertheless wholly in the spirit of Keynes.” With then this: “It looks as though
here to summarise the logic of the second candidate explanation of the pig cycle. Rather, we need some Systems Thinking, as follows.

Imagine a “pyramid” of subsystems, systems, supra-systems, and the supra-supra-system. We have already had to engage in such thinking: in Section 3.3, in respect of systemic risk; and in Section 3.4, when considering a delayed, potentially destabilizing, positive feedback looping around via the supra-system from the system and back to it. Now we need an extended version of that image, hence these four entities:

(i) **Subsystem**. The individual pig breeder (at the bottom of the pyramid).

(ii) **System**. One big man and his group of followers (pig breeders in receipt of credit from the given big man), wherein, perhaps, the big man emerges from among the number of pig breeders in the subsystem.

(iii) **Supra-system**. The clan, defined by adherence to just one of the various segmented lineage protocols, to which one or more of the big men belong, together with some, but not all, of the followers in the big men’s various respective groups. In other words, some of the followers indebted to one or the other big man in the clan would not culturally subscribe to that clan’s segmented lineage protocol.

(iv) **Supra-supra-system**. The totality (at the apex of the pyramid), comprising all the clans and all of their members; it is the totality of all the supra-systems, systems, and subsystems.

The harmony or tension between the expansive, big-man, individualistic outlook (I) on the world and the ideology of the segmented lineage (H) protocol is manifest in its bearing upon the individual pig breeder, at the bottom of the pile.

In an upswing in the pig cycle, there is harmony. To begin with, the big man activates (enters into) credit relationships that are validated by the lineage ideology. Only a small number of such potential relationships are possible, however. When this supply has been exhausted, the big man seeks accordingly to activate potential credit relationships from among the very large number that are not validated by the lineage protocol. In an upswing, nevertheless, there is still harmony. The big man, moreover, is always an I-type big man, always seeking to maximize the number of his followers — always.

The pig breeder is not so sure. He is, of course, prepared to buy into being a rational utility maximiser, according to the income eventually to be received from converting some of his breeding pigs into disposable pigs. But about every four years (so the empirically observed pig cycle suggests) he loses confidence and reverts to pledging his allegiance to the segmented lineage protocol. The protocol from which hails the big man relative to the protocol under which the given pig breeder is born, becomes then decisive. Where the big man has abused the protocol, this inherently generates the potential for the eventual conflict: of which of the two ideologies (I or H cryptically) is to be upheld by the individual pig breeder in determining how he is to act in the world. If the pig-breeder’s lineage differs from that of the big man he is following, the pig breeder’s H instinct may over-power the I rationality that has

catastrophe theory will allow us to write the general equation of which Keynesian theory, with its social constant, is the special case” (emphasis added).
been driving his husbandry practices. And he will ditch the credit relationship into which he entered with his big man. Where once the two rationalities were in harmony, or at least not discordant (from the perspective of the individual pig breeder), now they are in conflict. It is the individual pig breeder’s capacity to entertain diffidence about the future, at some moment in time, that diminishes the big man’s standing — one follower at a time. It is the individual agent at the bottom of the pile — the lowliest subsystem in the pyramid — who removes the metaphorical brick that brings the whole caboodle down.  

As others follow this one local removed metaphorical brick (of an individual pig breeder’s decision) — we might venture even to label that first decisive pig breeder as the oxymoron-sounding “lead follower” (of the big man) — the ramifications propagate upwards through the scales of the supra-system: up to the systems of the individual big men with their respective groups of followers; breaking through to the supra-systems of the clans; and penetrating eventually up to the supra-supra-system, at which scale the aggregate, global population of pigs and extended total credit, from Minyip to Talembais, are manifest. While the individual big man is focussing on matters strictly local to him (as he must), i.e., on maximizing the number of his followers (at what we have here defined as the system scale), so the potential number of additional credit relationships he can expect to extend is changing at the global scale of the supra-supra-system — and changing crucially as a function of what is happening to pig populations and other factors (the sequence of the phases in ceremonial gift-giving, for one thing; the emergence and demise of big men, for another). What is more, the big man’s expectations are now changing downwards, or so runs the argument in Chapter 9 of Rubbish Theory; Thompson (2017; Figure 40, p 210). At some point (as they say!), the metaphorical (macroscopic) “ground” of the supra-supra-system beneath the big man’s metaphorical (mesoscopic) “feet” of his system has morphed sufficiently for the big man’s expectations of his number of sustainable followers (number of credit relationships) to have dropped. He calls in existing credit relationships and ceases to seek out any more new relationships — but he is still an I-type through and through, unlike those renegade pig-breeder followers who have stopped buying into his I-type ideology in favour of reverting to the power and influences of their original H-type cultural, blood lineages.

To summarise, we see two things at work:

(i) **Cross-scale Interactions.** Switches of decision rules at the very bottom of the pyramid on behalf of the individual agent subsystems of the pig breeders well upwards to the system of the big men, through the clans, and on right up to the supra -

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30 Two points are to be noted in passing, one technical, the other of great import for the practice of Systems Thinking. First, technically speaking, the subsystem of the pig breeder can be unfolded (Russian-doll-like) into the sub-subsystem of the pig breeder’s brain and reasoning system (and it too in turn, unfolded likewise over and over again), where the H-instinct eventually wins out over the I-instinct (and here there is yet more cross-disciplinary reasoning and research, among neuroscience, plural rationality, and social anthropology; Verweij et al, 2015). Second, lifting up our gaze to contemplate multi-disciplinary Systems Thinking at its quintessential best, systems ecologist Holling has referred to what the bottom-of-the-pile pig breeder does as “revolt” (Holling, 2001). Holling’s pyramid arrangement is labelled a Panarchy (Gunderson and Holling, 2002) and the complementary manner in which the supra-supra-system “reaches down” to restore some kind of post-revolt “order” is referred to as “remember”. In none of Holling’s illustrious contributions, however, does the social-anthropological theory of plural rationality receive any proper account.

31 And abruptly, discontinuously so, just like that, as it would be, if we were pursuing an argument from the perspective of catastrophe theory (which we are not).
 supra-system of the whole, whose current status they change. The changing status of the totality propagates down through the supra-systems (the clans), to impinge upon the systems of the big men, hence their decisions. In fact, interactions happen within and across all scales, some having influences upwards, others downwards.

(ii) *Rational Adaptation.* When the pig breeder switches his allegiance from the *I* ideology to the *H* ideology, he is exercising (we would say) his capacity for Rational Adaptation (RA). He is swapping out one rationality for another. He is also demonstrating what was observed in respect of Figure 4 in Section 3.3 (observed by the IFoA Model Risk Working Party, that is), in the quite different transactional realm of the legitimacy of models for supporting actuarial decisions: that the four stances in Figure 4 are not intended as “psychological profiles” but as “generic perceptions that can be held by different stakeholders at different times, depending on their position within an organisation and the specific processes [transactions] they are involved in” (Aggarwal et al, 2016; p 257, with emphasis added). But when the pig cycle case study in the “Geometry of Confidence” was being written for *Rubbish Theory* (sometime prior to 1979) the pig breeder would have had only the one alternative rationality to which to switch. Besides, no *I* and *H* types were even present then in the book’s vocabulary. Today, post-**Cultural Theory** (1990), the pig breeder might, in principle, have three alternatives to choose from: an *H*, *E*- or *F*-type rationality (as indeed in Figure 4). In contrast, when the big man adjusts the number of his credit relationships, either up or down, he is not adapting his over-arching, guiding rationality in any way. He is still acting according to his enduring, unchanging, one and only *I*-type view of the world. He is still trying to maximise his followers, albeit under reduced circumstances. Would he be called “irrational” for that? Or, there again, would the pig breeder be accused of acting “irrationally” in allowing himself to switch from *I* to *H* (and back)?

Phrased alternatively in the contemporary light of the theory of plural rationality, we could say:

The big man (*I*-type) is utilising the same decision principle (or control rule, equivalently) in qualitatively different risk environments.

The pig breeder (*H*-type) is utilising different decision principles (different auto-pilots), with each ideally tailored to suit either of the (just two) qualitatively different seasons of risk.

As in the bull-bear switching simulated in the control studies of Yang *et al* (2016) above, and as too in the agent-based model (ABM) analyses of systemic risk in Heinrich *et al* (2019) in Section 3.3 (albeit less obviously so), the consequences of decisions at all scales reverberate around the totality. In particular, something dispatched as an output response *y* from the
system (at any scale) into the environment of that system (the totality) may ricochet around and then ultimately, through a circuitous feedback loop, come back to influence the system as a (more or less delayed) disturbance $d$.

Oh how complicated!

**Tying Up Some Loose Cross-disciplinary Threads**

Several threads have been drawn out from the three principal disciplines of anthropology, economics, and control theory, but not yet brought together, not evenly tentatively. So let us set about redressing this omission, as follows:

(i) *From Control to Anthropology.* The appeal to catastrophe theory, which defined the argument of Chapter 9 in *Rubbish Theory* (1979), is still there in *Organising & Disorganising*, specifically in Figure 9.2 of its closing chapter, which is what essentially justifies the book’s subtitle: *A Dynamic and Non-linear Theory of Institutional Emergence and Its Implications* (Thompson, 2008a; p 144). *En route* to that Figure 9.2, this is observed (on p 142): “One of the oft-voiced criticisms of cultural theory is that it leaves out power”. Courtesy of a Canadian engineer, and possibly one who is a control engineer (Nils Lind), a third dimension of “grip”, i.e., controlling power, may be deduced from the two dimensions of grid and group in Mary Douglas’s original analytical scheme for determining an individual’s social context. The manifestation of power is integral to the theory of plural rationality. A 3-D plot may thus be drawn (it is Figure 9.2 in *Rubbish Theory*), in which a curvilinear surface may be sketched in. It is a “morphogenetic field” in catastrophe theory. It stands over the 2-D plane of grid and group and is anchored somewhere up the third dimension of grip. Metaphorical movement of agents — big men and pig breeders — may be imagined up and down, along and across the morphogenetic field, as they gather in and occupy the camp of the $I$ types, or those of the $H$, $E$, and $F$ types. Such movement is all about the social dynamics that result from the exercise of power by one individual or group over another individual or group — by one ideology over another. And this would be power as exercised through persuasion and coercion; the growth in power for some; and the decline in power (over others) in some others, as evident in reneging, disillusionment, and fatalisation. We can immediately jump to

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32 Indeed, suppose we attach a colour to each of the rationalities: green for moderate ($H$), red for boom ($I$), blue for bust ($E$), and grey for uncertain ($F$). Now imagine the status of each and every subsystem, system, supra-system, and the supra-supra-system itself being capable of appearing as one of the four colours. We could imagine different degrees of herding, of all the totality’s components showing a great globe of red, for example, or just all the systems being red dots, or some red pin-pricks among the subsystems together with one or two red discs at the supra-system scale. Would these differing degrees and depths of red signal significantly different patterns of herding — different kinds of procyclicality calling for different combinations of micro- and macro-prudential actions in response?

33 Including, crucially, the camp of the special (+1) fifth (hermit) type of rationality, which will be the subject of a future proposal and research (the last recommendation of Section 5, in fact).
superimposing such on the dynamics of ceremonial gift-giving in New Guinea. And with but the slightest of pauses for thought, we can see how it relates intimately and comprehensively to the dynamics of power among the various decision influencers in an insurance company, hence possible forms of (better) governance for decision-making in the enduring presence of the insurance cycle with its four qualitatively different seasons of risk. Above all, let us suggest we ought to be able then to discern the wrong (and the right) forms of governance being brought to bear, in turn, on the exercise of Rational Adaptation.

(ii) From Anthropology to Control. With the passage of time (four decades, no less), something of a rotated and reversed spin has been introduced into Rubbish Theory (2017) vis à vis Cultural Theory (1979). It must necessarily appear, therefore, in the (new) Introduction to the second edition and, since nothing else in the body of the text has been changed over the decades, it appears as a Figure 0 (Thompson, 2017; p 4). It is, good grief, almost a control engineer’s block diagram. Its caption reads “The Basic Rubbish Theory Hypothesis”, such that there are three system blocks (for “Transient” objects; “Durable” objects; and “Rubbish”), with arrows signifying flows of objects between the three blocks. It is Rubbish Theory’s core hypothesis about a theory of value for economics, in other words. In order to facilitate explanation of the theory, the analogy of three cisterns is brought to mind in the text (pp 7 and 8), with flows of water from one cistern to another, which flows are controlled by taps: the control engineer’s “actuators”, that is. They are those devices that give physical realisation to the controlling choices u conceived of in the mind (or algorithm) of the system’s controller and issued therefrom as an (immaterial) signal to the actuator. For the totality (of the three cisterns) to remain as it is — a function of class, power, and status in society — the taps must be turned to exactly the “right” positions. (Alternatively, disruptive influences would seek to dislodge the taps from such favoured positions.) Under the theory of plural rationality, actors representing all four rationalities will have their metaphorical fingers on the taps.\(^3\) Four sets of “our likings”, therefore, but with only one actuator that — somehow, magically — can give physical realisation to the plurality of mutually opposed and contradictory wants and aspirations. In reality, and in practice, an insurance company implements but the one decision, not the plurality of candidate decisions. Nevertheless, one can see how one particular decision influencer, with more grip (or control, as in Organising and Disorganising) than another, might have her/his way. Good governance, we argue, should be the antidote to such a state of affairs.

(iii) From Anthropology to Economics. Rubbish Theory sought to rectify what it saw as a profound inadequacy at the very heart of economics (and was roundly rebuffed, suppressed, and trashed for that (Thompson, 2017; pp 15-16)). Undeterred, more on the matter was to be expressed, notably in a 2010 book on The Limits to Scarcity (see

\(^3\) Having had classical control theory and modern control theory, one is tempted to ask whether this might not be tantamount to a “postmodern” control theory.
Thompson (2010) as Chapter 7 in Mehta (2010). And more is yet to come, in a nascent body of work provisionally titled Institutional Evolutionary Economics (IEE), which is the subject of research in a second, companion project (2019-2020) for the US Society of Actuaries (on “Modeling the Variety of Actuarial Decision Making”).

(iv) From Anthropology to Economics and back to Control. The foregoing case history of the pig cycle in New Guinea (albeit a contemporary control theoretic re-interpretation thereof) was similarly a projection of anthropology into economics. It was intended to illustrate how Keynes had correctly taken individual motivation into proper economic account, but had limited his benefiting from such social anthropology, once he had expressed his fundamental psychological law (as defined above). He treated the marginal propensity to consume as a constant proportion of the marginal increase in income — as a time-invariant, constant (model) parameter, \( \alpha \), in effect. But by the time Chapter 9 of Rubbish Theory comes to a close (Thompson, 2017; p 215), this is concluded:

As the pig cycle goes through its violent ups and downs it is all too evident that the Enga pig-breeders are not disposed “by and large and on the average” to save a constant proportion of any increase in income that they may receive. The marginal propensity to consume is a constant only in the special case. In general, it varies as a result not of economic forces but of the social and cultural forces related to changes in the amount of certainty within the system — the tug-of-Hobbesian-war.

Control theory would then describe this as the model having a time-varying parameter: a parameter \( \alpha(T) \) changing (more likely) relatively slowly over macro time \( T \). It is something already encountered in the work of Yang et al (2016) (in Section 4.1), who referred to it so tellingly as indicative of structural change in the behaviour of a system. And this way of conceiving of structural change, whether in economic theory, economic systems, or, more immediately for us, a company’s risk environment, will shortly become especially important to the way Rational Adaptability may be understood and models deployed in supporting its processes and procedures (in Section 4.5 below).

To be able to form such cross-disciplinary connectives — some tenuous, others not; some of more immediate relevance to this present study, others not — are the essence of the predominant kind of System Thinking exercised in this project.

4.4 Rational Adaptability in ERM

Unlike the big man, who upholds but one Myth of Nature throughout his entire career (that of Nature Benign; a world of known knowns), the pig breeder may at times commit to this same Myth but, as his perceived risk environment changes (and changes qualitatively), is capable of swapping out the Myth of Nature Benign and replacing it with the Myth of Nature Tolerant but Perverse (a world of known unknowns). The pig breeder switches from a Maximiser to a Manager strategy. He changes not so much his mind (in the phrasing of the everyday) as his mind-set. We can say he adapts his rationality, his Myth of Nature. Nonetheless, if (in
economic affairs) one changes to not acting in the manner of “rational economic man”, one might well be accused of behaving irrationally. Either that, or (according to Behavioural Economics), a snap, and “erroneous”, decision \( u(t) \) may be made according to some sort of quick thinking dismissed as residing in the catch-all category of the irrational. Only then for the tide of rational (slow) reasoning to come flooding back in with a delayed decision \( u(t + \Delta t) \), thus to wash away the consequences of the earlier impulse and intuition — provided, of course, nothing significant about the decision-risk environment has changed during the passage of the dead time \( \Delta t \).

The theory of plural rationality renders null and void the catch-all, non-specific category of irrationality. In fact, how rational is the kind of adaptation we find in Behavioural Economics?

The complete thesis underpinning rational adaptation (RA) in Enterprise Risk Management is set out in a sequence of six articles published in what we cite as the InsuranceERM Compendium (2009-13). RA has been in the public domain, therefore, for roughly a decade. Indeed, it has matured to becoming the first topic addressed in a series of four AFIR-ERM webinars currently underway (Ingram, 2019). What is said of just its bare bones herein, then, has a very specific purpose: to home in on the quintessential challenge of what the pig breeder has to face, to change his mind “at some point” — to swap out his rationality — not to stay the course with (most obviously) the Maximiser strategy. The same challenge is implicit in the (key) penultimate article of the InsuranceERM (2009-13) Compendium (p 12):

The surprise game, as mentioned above, presumes that rather than “staying the course”, firms will follow the natural surprise process — changing strategy at some point in time after the environment changes and starts to give them signals that are disappointments.

Or, to express this more technically and formally, but still using the case history of the pig cycle in New Guinea:

What aspects of that leading follower-pig-breeder’s beliefs about the way the world works (his \( \alpha(T) \) for season \( T \)) and his perceptions of his world’s now “disappointing” behaviour \( y(t) \) (not \( y(T) \)) in micro time triggers the throwing of the switch (his \( u(t) \)) on that fateful day (\( t \))? What specific kind of surprise does he experience?

For as we shall now see, the following components of RA are already known to us:

(i) the strategies for each season of risk;

(ii) the “natural surprise process”;

(iii) the form of governance for company decision-making that enables, in effect, a faster, more correct choice of altered rationality for the altered circumstances; and

(iv) comparative financial numbers for company performance in response to this process.

**Current Status**

Nature Benign, Nature Ephemeral, Nature Tolerant but Perverse, and Nature Capricious are not falsehoods. Rather, they are the minimal representations of reality that allow each
rationality to claim it is indeed perceiving the world and making decisions — coping with enterprise risk, that is — in a rational, and not irrational, manner. Each rationality gets it right for some span of time, in the sense that its expectation of the world matches the actual world. Each way of conceiving of the world and acting in it has “its” season of risk (its T). The complement of which is that each way of acting in the world has (three) types of surprise, and usually not welcome ones.

As we have said, our scheme for characterising the insurance cycle has four phases (four seasons) marked out in macro time T: Moderate; Boom; Bust; and Uncertain (InsuranceERM; pp 2-3). Each of the four rationalities in our anthropological hypothesis about actuarial science gets its right for one of the seasons: risk managing for Moderate; risk seeking for Boom; risk avoiding for Bust; and risk absorbing for Uncertain. These comprise the first of our four bare bones of RA: the strategies for each season of risk. To list them, the risk-managing attitude of the Manager is realised through risk steering; the risk seeking of the Maximiser translates to risk trading; the risk-avoiding Conservator engages in loss controlling; and the risk-absorbing Pragmatist diversifies (InsuranceERM; Table 2, p 13).

Given the four sets of convictions about the way the world is, the natural surprise process (second bare bone) can be summarised in a 4×4 matrix: 16 elements, each expressing cryptically the surprise (or not) resulting from the mismatch (match) of the given Myth-holder’s “Expected World” vis à vis the “Actual World”. It is the typology of surprises presented as Figure 1 on page 9 of the Compendium of InsuranceERM articles.

Third, the form of governance for enhancing the company’s capacity for a timely adaptation of its rationality as one season (T−1) changes to another (T), is that which elevates deliberative quality to its utmost, as in Figure 3 (in Section 3.2 above). Henceforth we shall refer to this form of governance as clumsiness. A short exposition of it is given in the fourth of the six articles in the InsuranceERM Compendium (pp 12-13), but see also Verweij and Thompson (2006).

Last, and to be considered in somewhat greater detail, a selection of comparative financial numbers for company performance in responding to this surprise process, hence adaptation of a company’s rationality, appears in Table 3 on page 13 of InsuranceERM. They are taken from simulation studies with the Surprise Game (Ingram et al., 2012a). They may be benchmarked against the outcomes from the Game when companies never adapt their strategy and instead stay the course throughout (if they have not been ruined before the end of the Game, that is). This second group of numbers is presented in Table 1 of page 12 of the same (fourth) article. What can be observed is this. Three forms of RA are defined (also on p 12 of the Compendium):

(i) The “strong”, in which apprehension of the “disappointing signals” is immediate, as is identification of the new season of risk, as too the adaptation, which occurs with no transition costs. This is the theoretical — and unattainable — ideal of RA.

(ii) The “semi-strong”, in which the firm is indeed surprised (inherently a sudden, but delayed reaction), but is able to determine from the nature of the surprise, i.e., one of the 12 surprising elements in the typology of surprise, the actual risk environment, hence the specific adaptation that is needed. In this case, the company’s risk management strategy is “shifted gradually to avoid onerous real transition costs”.

56
The “weak”, when there is again surprise and again an adaptation, but here “without a clear idea of the underlying dynamics of the risk environment or the range of possibilities for risk [coping] strategies” (InsuranceERM Compendium; p 12).

Across five indicative rates of adaptation success — 100% (strong), 75% (semi-strong), 50% (semi-strong), 25% (weak), and 0% (weak) — the theoretical (and unattainable) strong adaptation achieves the highest rate of financial return, which returns are the most assured (least variable), and with the lowest rate of firm failures. In that there is no surprise. Who, then, would not want to implement Rational Adaptation, if only they could!

It is all a matter of timing. Technically, in the computational Surprise Game, simulated firms will change their strategies after three decision periods of having the wrong strategy, i.e., the firm can be wrong about the actual season of risk for $t$, $t+1$, and $t+2$, before one of the other three risk-coping styles unseats the currently (and, by then, persistently) failing rationality (Ingram et al, 2012a). This, however, is an externally imposed rule of the Game. The three-step delay does not somehow reflect the result of the simulated firm’s simulated reflexive enquiry into whether its risk-coping strategy is right for the times. The authors of the Game have simply imposed the rule. In reality, adaptation of the failing strategy could take more than three decision periods, perhaps fewer. But it is nevertheless technically a dead time $\Delta t$, with the accompanying implication of this being a possible source of all the life-like ups and downs in the Surprise Game results, which cycling is, of course, part of the central challenge our report is addressing.

**Getting the Timing Right**

Everything depends on apprehending that the “actual world” does not comport with, or conform to, the “expected world” (and at the earliest possible juncture, with an absolute minimum of dead time $\Delta t$). Assuming they have opened their minds to the possibility of entertaining plural seasons of risk, the upholders of each rationality may ask this of themselves: looking up from my day-to-day micro time ($t$), do I have a shred of doubt about my observations of the world’s behaviour — all the clutter of its $y(t)$ in micro time $t$ — being in my season of risk in macro time, i.e., in my $y(T)$? But that, surely, must go against the grain of every fibre in the bodies of all the various upholders. Yet people like us, of course, can rig our (necessarily prejudiced and biased) foresight models to ask approximations of these questions on behalf of each rationality. Indeed, we may ask not only which is the actual present season ($T$), but (archetypally) has the season changed recently, from $T-1$ to $T$, and may it change in the immediate future, from $T$ to $T+1$?

More incisively — noting the particular typology of the natural surprise process (its 4×4 matrix) — each Myth-holder could ask this:

Can I recognise my three kinds of surprise and, moreover, distinguish the one from the others, hence infer the current season of risk — and sooner rather than later?

For instance, with reference to Figure 1 on page 9 of the InsuranceERM Compendium, could the risk-seeking Maximiser distinguish among: (a) “skill is not rewarded”, hence the actual season is Uncertain, not Boom; (b) “total collapse”, hence the Bust season; and (c) “partial collapse”, hence the Moderate season?
In particular, people like us may ask how the use of a model, in spite of model risk, might enhance the Maximiser’s (or any other rationality’s) chances of discerning and apprehending her/his failing circumstances?

4.5 Model Support for Rational Adaptability

As in Section 3 above, we find ourselves again contemplating how to elevate deliberative quality in the exercise of governance over decision-making in an insurance company. This time, however, there is an added complication. For we are not seeking to address the matter of model risk when the risk environment is *unchanging* with time, but when it is and, moreover, changing in a more profound, qualitatively different way, i.e., in a *structural* way. The essential nature of the risk in this different setting is still that of flawed decisions being made because of the risk of the company’s incorrect grasp of its actual risk environment (and of this being ameliorated or exacerbated by the use of a model). Here, however, instead of enquiring “Is my rationality right/wrong for the times?”, we must enquire “In what specific way is my rationality wrong?”, because this determines which specific alternative rationality is to be activated. In contrast to the customary challenge of working out where the system is, we are looking for dissonance, but not just “dissonance period”, in the sense of seeking out anything and everything that does not give the actual behaviour of the system. The challenge, rather, is one of distinguishing among three particular varieties of mismatch between a company’s actual and expected world. Moreover, the more specific, more distinct, even idiosyncratic the three varieties of dissonance can be defined for the individual, specific insurer (and, in principle, for each of the four rationalities within the company), so much the better.

At this point, the reader may be reading between these lines and sensing that we are reaching out once again for the Regionalised Sensitivity Analysis (RSA) introduced and deployed for enhancing the governance of model risk in Section 3.4: that idea of a cultural sensitivity analysis; of touching plural bases (generating plural sets of candidate decisions) before finally enacting the one and only decision $u(t)$. And s/he would be quite correct. This we shall do. But there are important differences between the computational tasks of model support for Rational Adaptation (RA) in particular and model support for enhanced governance in general. In addition, there are echoes in the current challenge of previous (lengthy) encounters with the strongly similar challenge of apprehending apparent *structural change* in the behaviour of a system, as we have already been signalling. In their most complete form, these encounters with structural change in the behaviour of a system are laid out in *Environmental Foresight and Models: A Manifesto* (Beck, 2002).\(^{35}\)

The goal, to reiterate, is to enquire into the beginnings of how the company’s foresight model may be exploited deliberately to shorten the dead time (delay) between the actual change in the season of risk and the company’s apprehension of that empirical fact.

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\(^{35}\) Although their history goes all the way back to the beginning of the 1970s (as in Beck and Young, 1976) and extends up to nearer the present with Beck (2009) and Lin and Beck (2012).
Structural Change in the Risk Environment

We first came across the phrase “structural change” in the lengthy quote from the work of Yang et al (2016) on stabilising the pricing and reserving processes in an insurer. They were referring to its occurrence in association with their switching mechanism, which they intended should approximate the qualitative changes in macro time \( T \) between bull and bear conditions in the market place, i.e., in respect of the status of the supra-system surrounding the system of the individual insurance company. But to talk of “supra-system” here is to obscure something vital to what follows.

The bull and bear conditions are for Yang and colleagues their twofold classification of the insurer’s risk environment. The possible consequences for the insurer of qualitative changes in its risk environment are simulated through the grossly simplified binary switching sequence in the incoming stream of disturbances \( d \) impinging on the system (the insurer). Which disturbances, we may note in passing, occasion immediate, theoretically perfect Rational Adaptation, with neither surprise nor one iota of dead time \( \Delta t \). Vitally important is to observe therefore that structural change as such is not occurring within the focal system of the insurer, but in the surrounding supra-system of the insurer’s risk environment. What is more, the structural change of Yang et al (2016) is quite a restricted form thereof. If the risk environment is not bull, it changes to bear, and vice versa. It does not evolve in any way. For instance, it does not change from a classical bear to, say, a modern bear and, thereafter, to a postmodern bull, and so on. But it was not meant to. The studies of Yang et al (2016) had other purposes, which indeed they advanced quite substantially. Above all, the dynamics of their simulated risk environment were ancillary to the cut-out system of primary interest to them.

This leaves structural change much in need of a more technical, systematic definition, as follows (for the complete argument, see Chapter 4 “Structural Change: A Definition” (Beck, 2002; pp 51-60)).

In Section 2, the structure of the assembly of mathematical relationships for what are believed to be the workings of any system (insurer or the risk environment) — those internal mechanics that define how the \( d(t) \) are transcribed through the system to become the \( y(t) \) — is said to be “parameterized” through a set of model parameters \( \alpha \). If these constants are what they purport to be, the structure of the model is fixed. While the features of the external description of the system’s behaviour, the \( d(t) \) and the \( y(t) \), may flutter up and down in high-frequency micro time \( t \), the internal features (\( \alpha \)) determining its fundamental workings change not at all.

But the model is inevitably an approximation. The world is usually vastly more complicated than what has been captured in the model. If the inevitably simplified model is set the task of fitting the observed behaviour of the system, it might well be capable of doing quite a good job, providing the model’s structure has the capacity to flex and bend with the more persistent, systematic, qualitative observed changes over the longer term, in macro time \( T \). And a very important distinction is implied in this: that the high-frequency flutter of mismatches of the moment in micro time \( t \) are not of primary concern, but secondary to the slower unfoldings of persistent mismatches, such as the low-frequency persistent biases, or persistent and consistent under- or over-approximations of the high-frequency ups and downs in the observed system’s behaviour. Thus, to provide the model’s structure with such a judicious degree of plasticity, its parameters may be permitted to vary slowly with time, i.e., be understood as time-varying \( \alpha(T) \). In other words, and to make this definition of structural change succinct, we have this:
Qualitative structural change in the behaviour of a system may be accommodated through the proxy device of a model with a fixed structure of relationships that translate the incoming system disturbances \( d(t) \) into the outgoing responses \( y(t) \) — as gauged in the relatively short-term micro time \( t \) — but with parameters that vary relatively slowly over the longer-term macro time \( T \), i.e., as \( a(T) \).

That the nature of the high-frequency flutter in \( \{d(t), y(t)\} \) may change dramatically as a function of the rumbling, lugubrious low-frequency evolution of \( a(T) \) is quite unsurprising to anyone familiar with the technical rudiments of catastrophe theory (with what it refers to as “control parameters”). The notion is redolent too of the way in which some researchers are examining long-term GDP time-series in search of the progressive weakening of the restorative forces in an economy (Rye and Jackson, 2016).

What this definition of structural change implies for RA and the surprise process is (in part) therefore this:

Surprise is apprehended in the behaviour of the insurer’s disappointing signals \( y(t) \), but its roots lie in the apparent structural changes in the insurer’s risk environment, which (like the incoming switching sequence of Yang et al (2016)) may be made manifest in her/his model’s parameterisation \( a(T) \) of the variability of the insurer’s incoming disturbance stream \( d(t) \).

More specifically, the insurer’s risk environment of \( d(t) \), i.e., the ensemble of events that may strike the system, will typically be associated with probability density functions and with correlation functions for the co-variation of one event with another, as well as for the correlation in time of \( d(t) \) with \( d(t-1), d(t-2), \) etc. Such functions are populated with statistics and coefficients. Which is to say, they are populated by parameters embedded in the workings of the insurer’s model, which parameters may be permitted to vary with seasonal time as \( a(T) \).

In the original work on addressing structural change in the behaviour of environmental and climate systems, these were the archetypal questions being asked:

Have the “seeds of structural change been sown”, i.e., \( a(T) \), and are they evident in any model-based interpretation of the record of the past? Can then the dynamics of \( a(T) \) be characterised, hence used to explore whether the system has embarked imperceptibly on a path to eventual collapse or, for us here, to an imminent qualitative change in risk season?

To illustrate the possible nature of answers to these questions, \( a(T) \) could be reconstructed as appearing to switch between values of 0 and 1 for the now rather oddly contrived pattern of \( d(t) \) in the studies of Yang et al (2016).

Out of the handful of possibilities for tackling the detection of structural change in Beck (2002), there are two approaches that look especially promising with respect to RA: the one (RSA) because it can accommodate gross uncertainty and rather broad expressions of what constitutes the behaviour of the system; the other (a four-state Markov model) because of its simplicity.
Regionalized Sensitivity Analysis: Inverse Questioning with a Difference

We are not going to repeat the details of the RSA and how it might be used (as set out in Section 3.4), but rather sketch an indicative line of analytical reasoning.

Take the stance of the camp of F-type Pragmatists in the firm. Their three varieties of disappointing signals are summarised in the following Table (from the typology of surprises on page 9 of the Compendium of articles on RA in InsuranceERM (2009-13)):

<table>
<thead>
<tr>
<th>Expected World</th>
<th>UNCERTAIN</th>
<th>BUST</th>
<th>BOOM</th>
<th>MODERATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disappointing Signal</td>
<td>(NO SURPRISES)</td>
<td>(S1) Expected windfalls don’t happen – only losses</td>
<td>(S2) Unexpected runs of good luck</td>
<td>(S3) Unexpected runs of good and bad luck</td>
</tr>
</tbody>
</table>

Notational clarity and consistency are important in thinking through how the model of the company, when incorporated into an RSA, could be put to work on diagnosing the F-type’s surprises, i.e., (S1), (S2), (S3). To begin, let us label the disappointing signals in the company’s performance as \( y_{S1}(F; t) \), \( y_{S2}(F; t) \), and \( y_{S3}(F; t) \), in which we can see how the signals are distinguished according to surprise type and from the F stance and anchored in micro time \( t \).

Next, suppose that in the model qualitative changes in the F-type’s risk environment — her/his \( d(F; t) \) — are enabled through that F-type rationality to give the choice of associated parameterisation denoted as \( \alpha(F; T) \). In this, the “spin” on the model’s account of structural change in the risk environment is unmistakably that of the Pragmatist (F) and, in contrast to the disappointing signals, anchored in macro (seasonal) time \( T \). The pair \( \{d(F; t), y(F; t)\} \) amount to what the F-type observes — and, indeed, at the same time, ignores — of the “external description” of the system’s behaviour.

Parameterised thus, as belief \( \alpha(F; T) \) about the way the world works, and given the attaching take on the world about the F-type (its perceived risk environment and perceived disappointment), we may suggest this: that surprise S2, for example, should obtain “in reality” (hence the alternative decision strategy for choosing the \( u \) should be activated) when the probability of “realising” behaviour \( y_{S2}(F; t) \) is greater than that of realising either \( y_{S1}(F; t) \) or \( y_{S3}(F; t) \), all the gross uncertainty attaching to beliefs and takes on the world notwithstanding.

More robustly, looking beyond just the F-type camp and across to the upholders of the other three rationalities, the conclusion that the world is actually in the season of Bust (surprise (S1) for the F-type Pragmatists) could appear more sound if and when the corresponding RSA analyses for disappointing (or acceptable) signals about the company’s output performance, according to the respective model parameterisations of \( \alpha(I; T) \), \( \alpha(H; T) \), and \( \alpha(E; T) \), all point towards Bust as being the most probable realisation thereof.

But there is an interesting conceptual wrinkle in such reasoning. Two of the surprises for the Conservator E-type are tinged with envy: that the Maximisers (I), especially, prosper at the expense of the E types when the risk environment is Boom, while the Managers (H) likewise prosper at their expense when the risk environment is Moderate (see again the typology of surprise on page 9 of the InsuranceERM Compendium). Such behaviour has not been
presumed to have been incorporated in the Conservator’s respective take on the company’s performance, namely $y_{S2}(E,t)$ or $y_{S3}(E,t)$.

Suffice it to say, any such extensions of how RSA could be deployed in model-supported RA (conceptually, algorithmically, and eventually computationally) are something for the future, perhaps well beyond the present project. Nevertheless, we comment further on this matter in Section 5 (Recommendations).

**Seasonal Transition Probabilities and “Inclinations”**

In the light of Yang et al (2016), developing and mobilising a 4-state seasonal transition probability model might have much appeal (which it does). But for the time being a qualitatively similar, and equally computationally simple approach deserves to be touched upon. It has its origins in Beck (2002), specifically as Chapter 19 “Identifying the Inclination of a System Towards a Terminal State from Current Observations” (Kryazhimskii and Beck, 2002).

There, just a 2-state binary classification of behaviour was supposed: the “end” states of “survival” or “collapse” of the system in the long term. Technically, the analyses sought to detect any distinctly enhanced probability of the system’s inclining towards collapse (or survival), given sparse spans of current and very recent past observations of behaviour relative to the respective probability in the maximally uninformed condition of no access to any such observations whatsoever. The approach was tested on a prototypical case study:

Did the sparse spans of observations of small rodent population numbers in the vicinity of the Chernobyl nuclear reactor several years prior to the 1986 disaster-event suggest whether those populations had already embarked on a path towards collapse?

They did, according to this analysis of inclination, that is. In the financial world, the same approach has been employed to analyse whether there were any preceding “seeds of collapse” sown in the fluctuations of the US dollar/Russian ruble exchange rate prior to the collapse of the ruble in the 1990s. The approach has also been advanced in seeking to identify which company stocks are inclined to collapse in the (distant) future, given current fluctuations in their current and recent values (Hosseinizadeh and Guergachi, 2012). Methodologically, the approach can best be referred to as a matter of stochastic process modelling with inherent scope for “path dependence” in it.

The *prima facie* case for entertaining application of such an approach to our present challenge, of converging on theoretically perfect RA with minimal dead time, is very briefly as follows. A Markov state-transition probability model seeks to solve the following technical problem:

*Markov model*. Given plural (say 4) strategic states (seasons of risk) in which a system’s behaviour may categorically reside at any time $t$, what are the (4) probabilities (summing to 1.0) of that behaviour being in any one of these four states at time $t+1$? Or, equivalently, given that the system was in a particular state in the immediate past, at time $t-1$, what are the probabilities that it would reside in each of the four states at time $t$?
For comparison and contrast, the inclination probability analysis would seek to solve this companion kind of problem:

**Inclination probability analysis.** Given plural (4) strategic states in which a system's behaviour may categorically reside at any time \( t \), what are the (4) probabilities (summing to 1.0) of that behaviour being in any one of these four states at some time relatively far \( (f) \) into the future, denoted \( t+f \)? Or, equivalently, given that the system was in a particular season of risk in the relatively distant past, at time \( t-f \), what are the probabilities that it would reside in each of the four seasons at time \( t \)?

In this last hypothetical question we can discern some desirability in a company carrying along repeated analyses of inclination at each decision time \( t \). It has something of the "holy grail" of anticipating turning points in the market, of providing a leading indicator of some sort.

**Living in a Recursive Predictive World**

Notwithstanding the profound importance of RSA to the above way of problem-solving and to the book *Environmental Foresight and Models* (including the genesis of the inclination analysis), it has to be said that there would have been no such book (in 2002) had it not been for the algorithms of the then emerging (late 1960s) modern control theory, to which one of us (MBB) had been exposed from 1970 onwards (in the very same Computer Control Laboratory visited by Benjamin at the turn of 1970/1). They are the recursive algorithms of (on-line, real-time) state-parameter estimation, with their roots in mathematical filtering theory.\(^{36}\) In principle, they work as follows.

If — and it is a big “if” — time-series observations \( \{d(t), y(t)\} \) of the external description of the insurer system are accumulating over time in a readily available and suitable form, the recursive algorithm we have in mind would generate the sequence of estimated values for the model’s time-varying parameters \( \alpha(t) \). Implementing the customary form of the most complete of such algorithms (it rejoices in the name of the Extended Kalman Filter; Jazwinski, 1970), obliges the analyst to make a host of judicious choices about the magnitudes and correlative properties of the uncertainties attaching to the workings of the model, i.e., the uncertainties attaching to the state of our knowledge about the system. These are to be listed shortly.

First, however, we need to revisit the slight conceptual discomfort we have expressed earlier (in Section 3.3) with respect to the plot of the stances of our plural, cultural archetypes on the legitimacy of system knowledge, as encapsulated in a model, in Figure 4 (from Aggarwal et al, 2016). Its two axes refer to (low-high) legitimacy of modelling and (low-high) concern for model uncertainty. The four Rumsfeldian combinations of knowns and unknowns appear in the quadrants associated with each rationality. There is something not quite right about such a plot, for one thing in respect of the attachment of unknown knowns to the (fatalistic) Pragmatist stance. A small adjustment to the definitions of the axes enables the plural statuses of understandings of the system’s behaviour to be regularised in a more satisfying manner. Thus, in Figure 7 the two axes are now:

---

\(^{36}\) They are also the stochastic equivalent of the (deterministic) state observers referred to in Yang et al (2016) as the means to reconstruct estimates of the state of a company’s reserves.
“confidence in the model”, i.e., that “the past is well (poorly) explained/represented by the computational model”; and

“uncertainty about the future”, i.e., that “behaviour in the future may be ‘essentially similar to’ or ‘profoundly different from’ what happened in the past”.

In these very last words, we can see the need and challenge of deploying models, not only for generating foresight about the climate-environment system in the future, but also in enquiring into the nature of structural change and whether the system has already embarked on a path towards collapse. With respect to using a model in support of an insurer’s capacity to exercise RA, the same words (in (ii) above) should apply to her/his risk environment, albeit expressed in language compatible with this particular context: that the current season of risk will prevail (be essentially similar); or change qualitatively to another season (be profoundly different). In particular, and more formally, low and high degrees of uncertainty may be ascribed respectively to $d(t+1)$, to symbolize the future disturbances of the system.

Thus we come to providing a more complete and more refined account of all the uncertainties that must be specified in implementing a model within the recursive framework of an extended Kalman filter (EKF), not because we expect any such computation to be implemented (at least not yet), but because of how this illuminates the possibility for yet a further line of thinking through what Rational Adaptation (RA) in ERM may productively entail (in due course). Accordingly, we have:

**Uncertainties Attaching to the External Description of Model Mechanics**

(i) to the observations of the system’s inputs and outputs, $(d(t), y(t))$, that are therefore, in a sense, presumed to be known about and expressly accounted for in the model;

(ii) to those other (“covert”) incoming disturbances impinging on the system that are not observed, hence members of the (vast) assembly of entities that are the acknowledged unknowns belonging to (here) the
insurer’s risk environment (including those risks in the “dark” in Ingram’s (2009a) “Law of Light and Risk”);

**Uncertainties Attaching to the Internal Description of Model Mechanics**

(iii) to the estimates of the model’s parameters, \( \alpha(t) \), which, by definition are embedded in the \{presumed known\} relationships specifically expressed in the model;

(iv) to the degrees to which these parameters \( \alpha(t) \) are presumed to vary with time (technically, according to a stochastic process with specified variance-covariance properties); and

(v) to those omissions from the structure of the model that (nominally) cover the host of system workings lying outside of the \{presumed known\}, in the \{acknowledged unknown\} and beyond.

Given these categories of uncertainties, Figure 7 enables our arguments about their (numerical) specification to be guided towards the theory of plural rationality. A further kind of cultural spin can therefore be given to the way in which uncertainty is believed to be distributed among the features of the model, both in the essence of its internal description (in its parameters \( \alpha \)) and in the external description of the observed data, i.e., in its \{\( d, y \)\}. How well is “our” model known? How good are “our” observations of “our” risk environment (\( d \)) and “our” (disappointing) company results (\( y \))? How good is “our” grasp of “our” model relative to “our” grasp of “our” data? Such might be the considerations in quantifying the uncertainties.

In the upper right quadrant of Figure 7, then, we have what were previously called the Confident Model Users, those \( I \)-type model builders and users. For them, the past is well explained by the model and behaviour in the future will be essentially similar to that of the past. For these upholders of the Myth of Nature Benign, there is little uncertainty attaching to their choice of model parameters \( \alpha(I) \); and the future disturbances impinging on the insurer from the risk environment, nominally \( d(I; t + 1) \), will be essentially similar to the distribution of events observed in the past. Concomitantly, the stream of uncertainty being “injected” into the model from the covert disturbances from the risk environment is but a trickle, if not negligible; and likewise with regard to the uncertainty being injected into the presumptions about how the model parameters might vary with time. In other words, the \( \alpha \) are what sound (actuarial) science holds: they are truly constants. Finally, the model is so complete in its account of reality that the category of the \{presumed known\} is replete and that of the \{acknowledged unknown\} empty.

In the lower right quadrant, in the camp of the \( H \)-type Conscientious Modellers (people like us), Rumsfeld’s known unknowns translate into the following conditions. The past is again (reasonably) well explained by the model. More subtly, however, reconciling the model with the past (inherently) uncertain observations of company performance (\( y \)) has bestowed upon the model a “fingerprint” of uncertainty. This fingerprint is manifest in some of the parameters being better known and some less well known, if not rather uncertain; it will inevitably taint any extrapolations of the model into the future. In short, the fingerprint of calibrated model uncertainty attaches to the \( H \)-type’s choice of parameter values, \( \alpha(H) \). In addition, some of the model’s parameters may be acknowledged as capable of (apparently) changing with time, specifically in those quite tentative hypotheses incorporated into the model’s structure. And for these upholders of the Myth of Nature Tolerant but Perverse, the \{acknowledged unknown\} may be quite a full category. Conscientious Modellers also know that the future risk
environment, i.e., their presumptions about the ensemble of future disturbances $d(H; t + 1)$, will not be essentially similar to those observed in the past.

Moving across to the lower left quadrant in Figure 7, where stand the $E$-type Uncertainty Avoiders, they look out on the state of knowledge as follows. Many may be the covert, unobservable, unimaginable(!) disturbances striking their company, while those numerous future disturbances from the risk environment that can be imagined — their $d(E; t + 1)$ — will be utterly different from anything ever witnessed in the past. In effect, the basket of (presumed known) is nigh on empty, while that of the (acknowledged unknown) is full indeed. If push came to shove, the $E$ types might grudgingly grant that their choices for the model’s parameters, their $\alpha(E)$, should come with great and enduring uncertainty. For these upholders of the Myth of Nature Ephemeral, the model’s parameters might just as well trace out highly random walks into the future. Except that, if any of the values for the parameters in $\alpha(E)$ are close to a “tipping point” associated with impending catastrophe, disaster, and ruin, these parameters will exhibit the non-random determinism to trample over that threshold in the future, and sooner rather than later. If anything, the $E$ types hold, the past data have been over-fitted by the model — so typical of those modelling types! — not allowing them to “speak for themselves”, as it were. The past is not at all well explained by the model.

Fourth and last, the status of the knowledge of the world of those Intuitive Decision Makers who occupy the upper left quadrant of Figure 7, is that of the uncertainty between an old order that once may have obtained and any new order that some day in the future may come to emerge. Any model of such utter randomness does not make any sense. The past was a matter of pure chance, without reason. There are no tipping points, proximate or distant. If forced to make choices for a model’s parameters, the $\alpha(F)$ of these $F$ types might just as well buzz about in time as the pure white noise of an unbounded stochastic process. And yet, in their way of seeing the world, the future risk environment for these upholders of the Myth of Nature Capricious, their $d(F; t+1)$, will be just as it ever was in the past: plain old “uncertain”.

Given that the model may be parameterised in a plurality of ways, according to the four rationalities, and given that the (relative) uncertainties in the internal and external descriptions of the system’s behaviour may likewise be plurally expressed, does anything about the resulting reconstructed trajectories of the estimates of the parameters $\alpha(t)$ tell us something about the particular nature of the surprise? Put another way: given observations of recent past disturbances $d(t)$, and given model-generated estimates of the companion company outputs $\hat{y}(t)$, what wrestling and contortions in making estimates $\hat{y}(t)$ match observations $y(t)$ of the company’s recent run of disappointing results, yields what kind of informative reconstructed bendings, inflexions, turns, stretches, and gyrations (if any) in the companion estimates of $\alpha(t)$ — in particular, estimates of those $\alpha(t)$ relating to the parameterization of the risk environment $d(t)$? What gross, not-credible-to-“me” distortions in “my” model (“my” convictions-beliefs) must be wrought in order for it (them) to be matched (reconciled) with the company’s recent disappointing results? Must they, good grief, be so bent and corrupted and perverted as to make “me” switch to some other rationality? This, as it were, could be a very constructive use of the logic of an argument of reductio ad absurdum.

Do such possibilities add anything to what can be achieved in respect of exercising Rational Adaptability in a skilful and most timely manner in the complete absence of using any model? We merely bring them to the table, to park them there for the time being, before we proceed now towards crafting our practical recommendations (in Section 5 below).
Elegant Concepts — Practical Realities

Taking in a very deep breath, let us reflect on our journey across Section 3 and now Section 4.

We began with model risk being entirely out of consideration — within yet an enhanced form of governance, nonetheless (Sections 3.2). We moved on through the somewhat detached contemplation of whether or not a model should be used to support the shaping of a decision (Section 3.3); and then on further, in the interests of guarding against model risk, to deliberate rigging of the model in order to maximise the diversity of plural bases to be touched prior to enacting the decision (Section 3.4). Now, at last (in the current and preceding subsections), we have unfolded the various ways in which models — to facilitate exploration of the cultural diversity of plural rationality — can be deployed in a deliberately orchestrated manner in support of Rational Adaptability.

We cannot leave control theory behind, however, without making some remarks on two final (final!) notions embedded within it. For if there is a Rational Adaptability in ERM, there is an adaptive control in control theory. It was already apparent to Benjamin in the 1970s (Benjamin, 1982; p 286), when he observed:

> Even John Ryder, who wrote about adaptive control in actuarial work, seemed to miss the significance of Hilary Seal’s paper when he criticized it.

First, therefore, there is an especially elegant form of adaptive control (sometimes referred to as dual control), in which the insurer’s decision $u(t)$ would be chosen to combine steering the company in a desired direction (a component $u_{\text{Steering}}(t)$) with probing its incompletely understood behaviour, with a view to learning and reducing uncertainty, using a small element $\delta u_{\text{Probing}}(t)$, to give

\[
\text{Decisions } u(t) = u_{\text{Steering}}(t) + \delta u_{\text{Probing}}(t)
\]

Lest the probing should undermine the steering, control theory would rely on the next decision $u(t+1)$ following sufficiently quickly after $u(t)$ to arrest any untoward consequences of (erroneous) probing at the earliest possible juncture. If such a principal of control theory were capable of being realized in the practice of ERM — we observe — it would be a means of employing company decisions deliberately, as opposed to a company’s model, to cope, in effect, with model risk.

Second, there is also an elegant kernel of learning embedded at the heart of the EKF. The manner in which estimates of the model’s parameters ($\alpha$) are updated from one decision point ($t$) to the next ($t + 1$) is realized as follows:

\[
[\text{Updated model parameter estimate at time } t + 1] = [\text{Previous model parameter estimate at time } t] + [\text{Kalman Gain}] \times [\text{Mismatch between observed & 1-step-ahead prediction of system output } (y) \text{ at } t + 1]
\]

37 Ryder’s (1976) paper, to which Benjamin is referring, bears the title “Subjectivism — A Reply in Defence of Classical Actuarial Methods”. What would Ryder have thought, we wonder, had he had to be confronted with an anthropological hypothesis about actuarial science entailing a plural rationality?
In this, the Kalman gain is in essence a proportionality constant formed of some balance between the uncertainties in the external description of the system’s behaviour (such as the observed output $y$) and those in the internal description of its behaviour (notably the model’s parameters $\alpha$). Furthermore, all these uncertainties are continually evolving over time $t$. 
5 RECOMMENDATIONS

How might something of the above (both Sections 3 and 4) find its way into the actuarial practice of ERM, and sooner rather than later? And to recall, before responding to this question, all of the considerations of governance for model risk in Section 3 were grounded in a decision context where the prevailing season of risk (in macro time $T$) is not changing. All of the considerations leading up to the deployment of models in support of Rational Adaptation (RA) in Section 4 acknowledge (one way or the other) that the season of risk is fully capable of changing over the long term. In particular, RA is concerned with how to update company strategy when the season has changed (from $T-1$ to $T$) in the very recent past or, possibly, might change from $T$ to $T+1$ in the near future.

Here, then, are our recommendations. They are in part recommendations with implications for current practice and in part recommendations for further research. The latter split roughly between shorter-term work objectives, arising largely from the developments of Section 3 (governance for model risk) and those longer-term work objectives arising mostly from the developments of Section 4 (model support for RA).

5.1 Recommendations for the Short Term

(1) Putting Cross-disciplinary Systems Thinking to Work

Suggestions for Practice

Since early 2018 the IFoA has been preparing to launch a more enduring and focussed initiative in Systems Thinking. One of us (MBB) has been participating in this. At the time of writing (October, 2019), a “Financial Systems Thinking Innovation Centre” (FinSTIC) is about to be launched. Work reported upon herein — specifically that on the systemic risk arising from model “homogeneity” and regulatory “corralling” in Section 3.3 — has already been ear-marked as subject matter for a webinar, presentation, or podcast interview with the authors of Heinrich et al (2019) at Oxford University. One of us (MBB) has also been scheduled for an interview/podcast and similar opportunities for interviews with MT and DI are likely to arise in the coming months. FinSTIC’s goals are to promote the more tenacious pursuit of the kind of Systems Thinking illustrated throughout this report, to ensure that such thinking has a palpable impact on actuarial practice, and to promote the passing on of this skill to younger members of the profession (through curating materials for Continuing Professional Development, especially case studies).

Further Work

The challenge of communicating ideas effectively across disciplines — principally (herein) across social anthropology, economics, control theory, and actuarial science and actuarial practice — remains immediate with respect to this report. Some aspects of its more conceptual, theoretical, even quasi-algebraic arguments could benefit greatly from being more amply illustrated with examples from actuarial practice.

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38 Accordingly, we would like to circulate this report to Heinrich and colleagues at Oxford University to seek their feedback on it, in particular, on this Recommendation (1), as well as Recommendation (3) below.
Such was fully our original intention in respect of our discussion of how to exploit a company’s foresight model in order to elevate deliberative quality in governance for coping with model risk (in Section 3.4). However, researching and preparing such desirable illustrations have had to be sacrificed in the light of the constraints of time. The higher priority was simply to reason through (with all due care and attention) how the ideas of cultural sensitivity testing and the procedure of inverse questioning should work for actuarial science. We address this limitation, of more fully supporting our arguments with specific actuarial examples, in several of the following recommendations.

(2) Structuring and Orchestrating Governance for Coping with Model Risk

Suggestions for Practice

The principle of clumsiness, so key in assisting an insurer to progress from plural candidate decisions to the single, actionable decision, is already percolating into actuarial practice. In some instances, the use of model-generated supporting insights is already implicit in this process (without, of course, any form of computational cultural sensitivity analysis). Making this deliberately explicit, and then expressly orchestrating the cultural sensitivity analysis more formally, can be expected to give companies a capability for exercising clumsiness with an added element of foresight: a "looking-forward" capability. Which is precisely as Underwood and Ingram (2014) anticipated in respect of Own Risk Solvency Analyses (ORSA), to which we shall return below, in Recommendation (5).

Our strong preference in structuring appropriate forms of governance would accordingly be to re-engage with our colleagues (Tsanakas and Cabantous) in the Department of Actuarial Sciences, Cass Business School, City University.

Further Practice-proximate Research

It is clearly the case that the framework for handling model risk, in particular, casting the governance thereof according to the theory of plural rationality, has been gaining traction and is steadily progressing towards practice (witness Tsanakas and Cabantous, 2018). The challenges/responses and counter-challenges/counter-responses (as in the Tsanakas and Cabantous scheme; our Figure 6 herein, in Section 3.3) would, of course, have to be organised for all four rationalities, not solely from the stance of the H-type manager (as in Tsanakas and Cabantous). In practical terms, this alone would be an advance on what we understand to be the current state-of-the-art. To meet this need, the willingness and wherewithal of a company to organise, nurture, structure, and focus the associated debate will be required. Is there therefore some kind of “debating chamber” companies already have that might serve the purpose? How might the debate be orchestrated?

In response, we can only but observe the following. First, it is evident from our actuarial experience that survey instruments (questionnaires) have a role to play (Underwood and Ingram, 2013; Underwood et al, 2013; also Thompson, 2018), as do one-on-one interviews, at least indirectly (Tsanakas and Cabantous, 2018; Cabantous and Tsanakas, 2019). Looking further afield, to landslide management (as it happens), the governance, debating, and negotiating principles of clumsiness have been effectively mobilised in the form of “Expert Engagement in Participatory Processes: Translating Stakeholder Discourses into Policy Options” (Linnerooth-Bayer et al, 2016; see also Scolobig et al, 2016). In the context of environmental health and sustainability, we have experimented with the idea of putting the
theory of plural rationality and clumsiness to work in the setting of an agora (a market place), as opposed to a forum (a debating chamber) (Beck et al., 2011; see also Thompson and Beck, 2014). We opted for the vehicle of an agora on the basis of its being a place where each rationality could set up its stall, market what it is utterly convinced it has to sell, and seek to entice the “undecided” to “buy into” its way of problem-framing and problem-solving.39

Earlier on, in the same technical domain of environmental foresight and protection, but in a prototypical manner less deliberately self-aware of plural rationality, a survey-questionnaire and a day-long foresight workshop were experimented with for elucidating the greatest hopes and worst fears of stakeholders for the long-term ecological health of a lake just to the north of Atlanta, Georgia, USA (Beck et al., 2002b). The survey and workshop sought to elicit stakeholders’ aspirations for the future of the system, not their beliefs about the way it works. The workshop was the more successful device (Osidele and Beck, 2003).40 With the benefit of considerable hindsight, further reflection, and a greater infusion of plural rationality, a form of governance for such challenges — based integrally on the use of foresight models and reachable futures analysis (if not any scheme for coping with model risk) — was duly expressed as Adaptive Community Learning in Beck (2011; pp 83-101). There is good reason to suppose that such a structure of governance could itself be adapted for the present needs of ERM in the insurance sector.

(3) Exploiting Plural Beliefs: Implementing Cultural Sensitivity Analyses

Suggestions for Practice

We propose to open a discussion within Willis Towers Watson with respect to designing and experimenting with rudimentary, prototypical forms of the model-based cultural sensitivity testing introduced in Section 3.4. In this first instance, computational work would follow the simpler and more straightforward “forward-questioning” mode of cultural sensitivity analysis, as opposed to the more complex and advanced “inverse-questioning” mode (which will be the subject of Recommendation (7) below).

Further Research

Recommendations (1) and (2) do not call for implementing any specifically designed computational experiments. What, then, might be the requirements for undertaking a more complete, more rigorous cultural sensitivity analysis with a model?

39 And to puncture any impulse towards fractious unhealthy conflict the agora was billed as a matter of “good-humoured theatre” (Beck et al., 2011).

40 In fact, this was the case study in which “proof of concept” for the inverse analysis of reachable futures (using RSA) was first demonstrated. In passing, we note that the reachability of the stakeholders’ desired hopes for the lake’s long-term ecological prosperity was relatively more easily attainable than that of their worst fears. Technically, expression of the two future-behaviour outcomes was not according to the theory of plural rationality, but merely the result of statistical treatments of “sticky dot” exercises conducted with the sample of stakeholders gathered at the workshop. In this, the stakeholders were undifferentiated in any way according to their respective (differing) convictions about the way their lake was believed to work, i.e., according to the differing rationalities.
In its simplest form, this could involve nothing more demanding than parameterising standard model software according to each rationality’s take on the world. Our immediate need would be to undertake a “desktop” (non-computational) study of the potential of cultural sensitivity analysis using (and this is vital) one such standard actuarial model to provide background and problem-specific context (notably, as indicated above, one of the models employed by Willis Towers Watson). Avoidance of the kinds of systemic risk illustrated by Heinrich et al (2019), and feared by companies using standard software packages in the London insurance market (Tsanakas and Cabantous, 2018), might usefully give the desktop study a more urgent relevance. Certainly, we may note that our experience of the 2016 BIS Seminar on “Solvency and Global Capital Standards for Insurers” inspired the provisional conclusion that models should be used deliberately for, as we put it in Section 3.3, dismembering group think. Which is to say, we should be engaged in pre-emptive investigatory examination and challenge, in respect of governance for coping with model risk. This would be the touching of plural bases (not just the one), where these are bases pushed apart as widely as possible by the use of plural rationality.

However, certain practical limitations on the effectiveness of cultural sensitivity analyses can already be anticipated. In particular, the virtue of complete authenticity in articulating the various beliefs about the way the world works across to the numerical model parameterisations may be difficult to achieve, especially in respect of the $E$ types and $F$ types who would, in theory (and in principle), have no truck with the use of models and probably no respect for the outcomes of any analyses with them. And that has important implications, to be addressed in Recommendation (5) below.

(4) Season-sensitive ERM

Suggestions for Practice

Irrespective of whether a recent-past or imminent change of season in a company’s risk environment is suspected (changes over macro time from $T-1$ to $T$, that is, or from $T$ to $T+1$) insurers should undertake what we shall call “season-sensitive” tests of their risk-coping strategies. Significantly, this would oblige a firm to examine all the suggestions for practice in the preceding Recommendations (1) through (3) from stances quite other than that of the predominant Manager ($H$) type, who, so instinctively, is generally identified with the “M” (the “Management”) in ERM.

Further Research

Manager types — people like us, as we have (wryly) observed — believe in the systematic process of developing and employing models in support of decision making. In contrast to their companion Confident Model Users, they acknowledge the presence of model risk and the need to design procedures for coping with it (and expressly so). They may indeed have strong sympathies with the instincts of those archetypally hierarchical agencies, such as the Federal Reserve (2011) and HM Treasury (2013), who have been urging upon the banking and insurance sectors the need to do something about model risk (hence the IFoA Working Party on Model Risk; Aggarwal et al, 2016; Black et al, 2018). Yet nothing in Recommendations (1) through (3) implies enquiry into whether the current frameworks for coping with model risk should differ as a function of whether the season of risk ($T$) is Moderate, Bust, Uncertain, or Boom.
So what, we ask, might the $H$-type decision-influencers do in respect of ERM when confronted — finally, post-surprise, and doubtless with some dead time $\Delta t$ — with the actuality of their company’s risk environment being not their favoured Moderate but instead Uncertain, say, as in the last few quarters and years of the time-series of US house-price data shown in the *InsuranceERM* Compendium (2009-2013; p 3)? What would coping with model risk mean for the Manager types, when the prevailing circumstances are (truly) those of the deeply unsystematic predictability of, in effect, a disappointing signal of pure white noise? How should the challenges/responses and counter-challenges/counter-responses of Recommendation (3) be organised? For not only have they been focussed hitherto solely on the world as perceived from the Conscientious Modeller’s (Manager’s) perspective — witness Figure 6 in Section 3.3 — but also the attaching perspective has been anchored in the micro time ($t$) of relatively high-frequency decision making, suspended therefore outside the macro time ($T$) of the relatively low-frequency seasonal changes in a firm’s risk environment.

The present recommendation is intended to redress this “oversight” in a preliminary and altogether rather basic way. Do the foregoing questions even have merit, we should ask ourselves, hence are they worthy of any more detailed investigation?

(5) “Imperatives” for Heeding Model-generated Insights

Suggestions for Practice

Own Risk Solvency Analysis (ORSA) is now in place in many jurisdictions around the world, in particular in the EU and the USA. Formal considerations of ORSA — when integrated into the practical procedures for re-structuring governance for coping with model risk in Recommendation (2) above; and given added importance by those considerations of the practical challenges of systemic risk entailed in Recommendation (3) — ought at least to be a better incentive, if not imperative, for more of the four rationalities to heed model-generated insights than just the manager ($H$) types. The pressing concern is to address the decision-debating deficits, hence decision-making problems, that arise from what we have observed of the holders of three of the four rationalities wanting models, above all, to be “compliant” with their intuitions and wishes.

Further Research

In our earlier work on assembling and analysing the empirical evidence of the presence and operational influence of plural risk rationalities in insurance companies (Underwood et al, 2014; Thompson, 2018), some decision-influencers were found to be naturally drawn to the use of models (the Managers), while all the others (Maximisers, Pragmatists, and Conservators) tended to be repelled from such activity — an observation surely worthy of more careful interrogation. Manager $H$ types, we might conclude, should be interested in, for instance, the outcomes of cultural sensitivity analyses of the company model, the others not.

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41 That this empirical evidence is inconsistent with what was hypothesised in the Phase I report of the IFoA WP on Model Risk (Aggarwal et al, 2016), specifically in respect of members of the Maximiser camp who were there designated Confident Model Users (in Figure 4 of Section 3.3), is something that will require further careful re-examination. As for certain rationality types being repelled from the use of models, the use of models (at least environment-climate models) can indeed be quite vehemently resented by some stakeholders and their inevitable uncertainties exploited to trash their results and ensuing insights (Beck, 2014; pp 120-125).
Except that increasingly regulators are insisting on companies acquiring and using models, as we have seen from the 2016 BIS Seminar (as reported in Section 3.3). As if to echo Philipp Keller’s observations at that Seminar, manager types will want to get their models right, while others will (cynically, according to Keller) want their models and the modelling results to be compliant: in the sense that, for example, the computational results are deemed to underestimate the relevant risk or (in the case of the F types) endorse their past flawed decisions retrospectively.\footnote{This too will require further re-examination. For only those labelled “Intuitive Decision Makers” in Figure 4 (Section 3.3), i.e., the F-type Pragmatists, in contrast to the E or I types, would seem to be the prime suspects for wanting the results of the model to be compliant.} If all this is possible, and if the influence of any of the solidarities of the F, I, or E types is in the ascendancy in a company at the given point in the Insurance Cycle (as described by Underwood and Ingram (2014)), then model-generated insights are likely to be entirely ignored. The interaction between the use of models and the social-power dynamics in the company (or in some regulators, as observed in the 206 BIS Seminar) becomes important.

Past experience from the selling of Variable Annuity policies in the USA prior to the bursting of the dot.com investment bubble in 2001 ought therefore to be persuasive, we submit, in respect of introducing incentives or imperatives for the heeding of model-generated insights by all parties. We offer up for consideration this speculative narrative.

Regulatory standards for capital requirements to service the Variable Annuity policies were essentially non-existent, under the assumption that individual customer policy holders would bear all the associated risk. "Astute" companies, influenced predominantly by adherents of the compliant stances, packed the policies with additional risks in the form of guarantees on the performance of the policies. These high-risk products drove the alternative low-risk contracts out of the market — those contracts designed and sold (we conjecture) by companies dominated by the H-type managers. Yet the belief within the companies selling the high-risk products was that the company was bearing none of the risk. At no point did any of the prevailing I, E, or F types, with their presumed disdain for the use of models, have any interest in getting the company’s actual risk exposure right. And when affairs in the market place eventually took the inevitable turn for the worse, such types could well have promptly placed the blame at the door of the regulator.

Since our desire would be for all four rationalities to at least tolerate the use of models and, ideally, heed their outcomes, the role of the regulator may be crucial here. When Underwood and Ingram (2014) were looking ahead to the imminent need for insurers to undertake their Own Risk Solvency Assessments (ORSA), the requirement of "looking forward" was one of their two priority concerns (the other being that of "shifting responsibility"). They expressed their concern thus:

Looking forward. The ORSA takes a forward-looking approach. Whereas previous practice looked backwards to assess whether surplus was sufficient at the end of the last year, under ORSA insurers must look at solvency for the next year or even the next several years into the future.

This looking forward, now required through the implementation of ORSA, implies some deployment of a model to generate estimates of future surpluses, the $\hat{y}(t + 1), \hat{y}(t + 2)$ and so on at the future decision points, with each rationality perhaps generating its own spin on these forecasts — and duly obliged by a regulatory framework to do so and take note of the results. Of course, the burning issue in any such looking forward would be to detect whether a qualitative change of season in the risk environment is imminent, i.e., from the current season.
With a view therefore to enlarging the extent to which model-generated foresight is heeded — as an insurer exercises debate and governance for progressing from plural candidate decisions to the one and only actionable decision — a closer, even more complete examination of the contemporary regulatory environment will be needed. Indeed, something similar will be the subject of subsequent Recommendation (8) below.

(6) Elaborating and Enhancing the “Disappointing Signals” of Surprise

Suggestions for Practice

Any means of shortening the “dead time” (our $\Delta t$) in the ways companies respond to surprise when the season of risk has (in actuality) changed, will enhance actuarial practice (Underwood et al, 2013). The typology of surprises set out in *InsuranceERM* (2009-2013; p 9) and quoted in part in Section 4.5 (under “Regionalized Sensitivity Analysis: Inverse Questioning with a Difference”) is capable of fruitful elaboration in greater detail — which we strongly commend.

Further Research

Exceptionally, with respect to model support for RA and the developments of Section 4, we believe early progress in the short term can be made in defining and refining the data requirements for the “natural surprise process” of the (current) framework for RA set out in Section 4.4. To summarise and recall, model support for RA will require forms of empirical observations for enabling the following functions: apprehending surprise and diagnosing its rationality-specific nature; discerning a recent and/or imminent transition in the season of risk ($T$), and sooner rather than later, with minimum dead time $\Delta t$; and divining what may be happening to the social-power dynamics among decision-influencers within a company — not only for the purposes of identifying changes of decision strategy, but also for inferring the possible presence or onset of one kind of potentially risky fatalism or another (i.e., one or another kind of risky group think or closed hegemony).³⁴

Our point of departure into such an assessment will most probably be via the data assembled for our companion (2019-20) Society of Actuaries (SoA) project on “Modeling the Variety of Actuarial Decision Making”. These data refer to a large number of US insurers and include relatively complete records over the past 10 years for the performances of 192 “mutuals only” companies. Premium growth, authorised control level risk-based capital (ACLRBC), the ACL risk-based capital ratio, the combined ratio (of $(\text{claims} + \text{expenses})/\text{premium income}$), and the returns on average equity are indicative of the various time-series available for

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³⁴ Irrespective of the rationality to which we once cleaved so passionately, we are all capable of becoming “fatalized”: to withdraw thus from the active debate and discussion that should accompany good governance and elevate deliberative quality as progress is made from the plural candidate decisions for an insurer towards its eventual single, actionable decision. And, to note, we are here using “fatalized” in its familiar colloquial form, as opposed to the interpretations and logic being assigned herein to the $F$-type rationality. Besides, we are increasingly coming round to seeing rather more of the “positives” than the “negatives” (slurs) in this $F$-type rationality (as signalled early on in Section 3.3). If, therefore, it were somehow possible to apprehend (from some kind of observations) that very few company employees were subscribing to one rationality or another, this ought to be troubling, ergo risky.
investigation. In principle, the objective would be to develop tighter, more specific, more elaborate data-based expressions of the “disappointing signals” of company performance given in the typology of surprises on page 9 of the Compendium of articles on RA in InsuranceERM (2009-13), one illustration of which is given in Section 4.5.

We speculate that, in the aggregate, disappointment could be anything below, say, the 20th percentile of the sample for any given time-series (depending on the sense of the observed measure), while surprisingly good results might be anything above the 95th percentile. But, of course, what we really want to know is when the performance of an individual insurer drops from, say, average to disappointing, which we hypothesize might not be too difficult a task. Then, more incisively, we should want to know whether this shift occasioned any accompanying change of company strategy (change of risk-coping style) and, if so, from what clearly identifiable rationality (decision strategy) to which other just as clearly identifiable rationality. This latter pair of tasks, we conjecture, would be considerably more difficult to discharge. And, we repeat, we are indeed making here a substantial speculation.

Yet there is a more basic problem. What exactly do the “disappointing signals” comprise? Are the data streams comprising the disappointing signals the same facets of company performance for each rationality — bearing in mind the basic (even defining) propensity of each rationality to heed some things about the behaviour of the world and deliberately ignore others?

Again, therefore, a significant challenge can already be anticipated, here now in respect of strategy detection. For example, to recall from Section 4.5, some of the entries in the matrix of the current (2013) surprise typology — notably for upholders of the conservator E-type rationality, who resent “others gaining at their expense” — call for an empirical awareness of the comparatively successful performances of companies whose risk-coping decision strategies are anything but those of these E types (namely, the H types or I types). In other words, empirical observations (of some kind, obtained from somewhere) would need to be capable of strongly implying the prevalence of the workings of these alternative decision strategies within and (more vexed) without the focal company. Such issues will need to be carefully thought through, and in some depth, before embarking on any computational analysis (with an RSA).

5.2 Recommendations for Further Work in the Longer Term

Various constraints on any further work to follow on from the present project are already apparent. They are principally these:

(i) the availability of appropriate data, as above in Recommendation (6);

(ii) the availability of suitably skilled personnel, in respect, say, of competences for elucidating the beliefs and aspirations of the four rationalities, as in Recommendation (2);

(iii) the availability of sufficient time for conducting the kinds of computational sensitivity analyses we are proposing, especially in Recommendation (7) below regarding inverse analyses with RSA;

(iv) the constraints of inflexibility in standard commercial software packages, again with respect to implementing an inverse RSA; and
(v) the inevitable constraints arising from the social-power dynamics among decision-influencers in a company, not least in the heeding of model-generated insights in support of decision making (Recommendation (5)).

Nevertheless, the following are our priorities for further lines of enquiry and research.

(7) Exploiting Both Plural Beliefs and Plural Aspirations: Reverse Sensitivity Testing with a “Cultural Spin”

Further Research

In the inverse-questioning mode of a sensitivity analysis — that form of analysis introduced in Section 3.4 for identifying those current risk factors that are "mission-critical" in respect of realising future aspirations (both hopes and fears) — authenticity will again be important, and doubly so.44 For whereas a forward-questioning sensitivity analysis asks (algebraically) "What changes in model outputs, $\delta y$, result from what specified changes in model parameterization, $\delta \alpha$?", inverse questioning asks “What particular parameterisations $\alpha$ are necessary for discriminating whether a pre-specified $y$ is attainable (or not)?”. Plural rationality will need to be accommodated in the computational exercises in two ways (hence the “doubly so” of the difficulty), with respect to: (a) beliefs about the way the world works; and (b) aspirations for where any rationality wants the company to be in the future (and where it does not).

Unsurprisingly, the associated computational burden will also increase, and perhaps even more explosively so than in the forward-questioning mode of a cultural sensitivity analysis. A bewildering variety of bases to be touched may arise, merely from the variety of combinations of beliefs and aspirations. It is also quite likely that standard company software systems may not permit, facilitate, accommodate, or support the RSA format. But the nub of what the inverse questioning of RSA does seems to us so very important. It is this: it identifies plural sets of mission-critical risk factors in the model (the $\alpha$), subject to acknowledging possibly gross uncertainty attaching to current knowledge of these factors (due acknowledgement of model risk) and just as gross uncertainty about the quantitative, numerical translation of each rationality’s aspirations (expressed in terms of model outputs $y$). If the uncertainty is overwhelming, so be it. No clear mission-critical risk factors will be identified.

In order to make the relative novelty of the inverse-questioning mode more familiar to practising actuaries, we shall refer to it as “reverse sensitivity testing”, which in fact is how Pesenti et al (2018) have recently described a similar approach, along with their accompanying question of “What Does it Take to Break the Model?”. Technically, their analysis may be summarised as follows. With reference to a simple insurance portfolio model employed commercially by an industry participant in the London insurance market, these authors identify which specific risk factors (model parameters $\alpha$) appear to be most strongly associated with, i.e., most influential in or most critical to, any marginal shift in the (future) output status ($y$) of the company, as gauged by the Value at Risk (VaR) and Expected Shortfall (ES) measures. Specifically, they test for an 8% increase in the 95th percentile value of the

44 It would also be important for someone, somewhere to be aware of those risks unattended to and growing furtively in the dark (Ingram, 2009a) and for them to be included in the model, as potentially mission-critical risk factors.
VaR and a 10% increase in 95th percentile of the ES. For commercial reasons the particular risk factors found to be most “active” in facilitating such marginal degradations in company performance cannot be named in the paper. But the paper tells us two important things. First, such a reverse sensitivity analysis can be implemented with a standard software package for an actuarial model, although the computational procedure of Pesenti et al is not that of an RSA, nor does it make any reference to plural rationality and the diverse risk cultures. Second, the problem these authors set for themselves is this: “What marginal changes in which of the model’s parameters — i.e., which $\delta \alpha$ — are key to facilitating the pre-specified marginal changes $\delta y$ in the model’s outputs?”. The marginal change $\delta y$ is referred to as an “output stress”.

What the RSA would do in the stressed-scenario analysis will be set out shortly in the next recommendation. For our concern in the current recommendation is to indicate instead that something like an RSA might be made to work computationally with standard commercial actuarial software. Further, one of the vital tasks of using a model (and RSA) in support of RA in the present recommendation, is for diagnosis of the rationality-specific surprise a company perceives it has encountered. This was set out in Section 4.5, where we referred to what is needed as “inverse questioning with a difference”.

To be more precise, for this purpose of surprise diagnosis, the RSA might be applied to the following. Let the expected company performance, prior to the dawning of any surprise among its employees, be denoted plain $y$ algebraically, contra the (rationality-specific) surprisingly disappointing company results $y_{\text{surprise}}$. The challenge then would be to work out what surprise specifically could have occurred — in principle — by implementing an inverse RSA of the reachability (or otherwise) of $y$ and the plural $y_{\text{surprise}}$ (all 12 varieties thereof). We may appreciate from this why someone in the company might protest at the lack of time for making a timely diagnosis and decision in the face of such a time-consuming computational burden. Or not protest, as the case may be, according to the perceived severity of the surprise.

In short, it may be helpful to close this recommendation with the following analogy. Inverse RSA may be conceived of as a fishing net, whose purpose in part is to catch and bring to the surface mission-critical risk factors (embedded as the parameters $\alpha$ in a model). Differing styles of fishing nets (models) may be designed to catch different types of “fish” (risk factors), with the different (cultural) design choices being available for the extent (coverage) of the net-cum-model and similarly different choices for the net’s mesh size.

(8) Formulating Regulatory Solvency Analyses to Expand the Heeding of Model-supported Risk Coping

Further Research

To return thus to the problem context addressed by Tsanakas and Cabantous (2018), if the company’s actual risk exposure is defined as $y_{\text{actual}}$, a companion stressed scenario for the company may be expressed numerically as future outcome-behaviour $y_{\text{Stressed}}$. For Tsanakas and Cabantous, we note in passing, the numerical specification of the (RSA) $y_{\text{Stressed}}$ would be derived on the basis of something akin to the additions of the output stresses for the VaR and ES of the given company’s status.

For our purposes, however, we speculate that the regulator should specify a set of the $y_{\text{Stressed}}$ to be applied to all insurers, or at least the G-SIIs (Globally Systemically Important Insurers), much as is now the case for banking institutions in some countries. Each such subject
company, with its own (internal) model, could then apply the inverse analysis of RSA to both its actual exposure $y_{\text{Actual}}$ and to the stressed scenario $y_{\text{Stressed}}$. At the very least, this should provide a benchmark for judging the financial solvency of each regulated company: a statistical measure of the reachability of the stressed behaviour $y_{\text{Stressed}}$, i.e., something about the likelihood of the potentially ruinous loss — something, in fact, rather like the €40B loss imagined at the 2016 BIS Seminar (for a company like Swiss Re; see Section 3.4). More to the point, arguably, the regulator could exercise a more detailed supervisory responsibility of forcing companies (and the non-$H$-type risk-coping adherents in the company) to heed the outcomes of their models. And actuarial professionals should be engaging with regulators on precisely such.\footnote{Although we are well aware of the dismay yet more regulation might occasion, hence more regulatory-compliance work, as observed in Black et al (2018; p 32, paragraph 5.1.34).}

Faced with good information about their (mission-critical) risks — the most simple-minded premise underpinning the Solvency II framework of regulators in Europe — decision-influencers in insurers will act prudently. Failing that, disclosures to regulators and to the market should force the taking of appropriate actions.

\textbf{(9) Exploiting the Principles of Control System Synthesis}

\textit{Further Research}

Some core principles of classical and modern control system design were introduced in Sections 4.1 and 4.2. There, the foundations of control in feedback and, less so, feed-forward control were touched upon. The shaping of (feedback) control — according to the three qualitatively different components of Proportional (P), Integral (I), and Derivative (D) actions — was introduced. Our view is that the full scope of this so-called PID control, aged though it may be, has yet to be explored in the actuarial decision-making of insurers and should indeed be so explored. In their collaboration between 1970 and 1982, Benjamin and Balzer made a start. It is high time, we believe, to build further on their platform.

Let us suppose, therefore, a company decision context in which information about output accumulated company surplus ($y$), for instance, is to be fed back into the way in which the firm’s input premium-setting or reserving decision ($u$) is determined. In this setting, the elements of PID control allow the insurer’s decision to be made up of:

\begin{itemize}
  \item[(i)] Something, via the P component, exploiting current output information at the current decision point $t$;
  \item[(ii)] Something else, via the I component, benefiting from past output information attaching to decision points $t$, $t -1$, $t -2$, and so on, back into the past; and
  \item[(iii)] Yet something else, via the D component, accounting for future output information attaching to decision point $t +1$.\footnote{Which technically derives from choosing a central difference approximation for the current derivative of the output at time $t$.}
\end{itemize}
What is important for us, however, is not so much the corpus of mathematical techniques available for choosing any mix of PID elements in the decision rule, but the concepts that lie behind them. Who knows, we are asking ourselves, whether and how the instincts for “retrospective”, “in-the-moment”, and “anticipatory” decision-making might be distributed among our four rationalities, hence fruitfully exploited in coping with model risk for ERM?

In a similar, but probably deeper, cross-disciplinary spirit, we have likened the problem of RA to that of detecting and diagnosing structural change in the behaviour of a system (in Section 4.5) and remarked upon how both that other problem and its possible solutions draw upon ideas from the body of (early) modern control theory (as illustrated in Environmental Foresight and Models: A Manifesto; Beck, 2002). Perhaps the simplest starting point for transcribing anything of that earlier work into the domain of actuarial modelling for supporting RA is what we have referred to as an inclination analysis — as opposed to the more familiar analysis (and prediction) of the seasonal changes in a company’s risk environment using a Markov-chain, state-transition model.

Likewise drawing upon the body of modern control theory, we are of the view that the principle of dual control — which prudently combines the functions of steering the company’s performance and probing the model’s unknowns (the company’s risk factors) in the composition of the company decision (its u) — may have a great deal to contribute to the way in which models are used to support Rational Adaptability (RA). And we freely acknowledge that the principle of dual control has been summarised at the end of Section 4.5 under the deliberately challenging sub-heading of “Elegant Concepts — Practical Realities”. How dual control might just work in practice, nevertheless, has already been discussed and visualized in the exposition of Adaptive Community Learning in Beck (2011; pp 83-101).

Whatever the case, we include in the present recommendation our intent to seek feedback on the more modern aspects of control system synthesis for actuarial decision-making from Yang and colleagues at Liverpool University (not that their simulation study exploited the principle of dual control).

(10) Invoking the Fifth Rationality: the Adaptor

Further Research

Coping with model risk is most problematic at the turning points (transitions) in the Insurance Cycle, or any cycle for that matter. Most models tend to fail badly at such times. In this sense, it might well be concluded that the real issue for us is the use of models to achieve the theoretical ideal of Rational Adaptation (as nearly as possible). Moreover, while coping with model risk has been central to our discussion of governance for ERM in Section 3, it has largely been implicit in our treatment of model support for RA (in Section 4). But it was implicit therein only in the sense that a cultural sensitivity analysis is implied in the inverse RSA, whose potential role has in fact been so prominent in Section 4.5, as too in the preceding Recommendations (6) and (7).

We ask, therefore, which rationality — the I-type risk-seeking Maximiser, the H-type risk-managing Manager, the E-type risk-avoiding Conservator, or the F-type risk-absorbing Pragmatist — bears responsibility for steering the company through thick and thin, season in season out, over the longer term, in macro time T? Who has her/his eye trained on the resilience of the company in the longer term: of not just surviving a Bust season in the market, nor merely bouncing back from it to resume “business as it was before the Bust”, but of
bouncing forward to attain a yet higher level of performance? Who has responsibility for trying to discern the imminence of some “new order” in the season of Uncertainty?

None of them is our answer. Secreted in Section 3.1, and announced there as to become noteworthy at the very close of our report (right here), is mention of the fifth rationality of the so-called hermit, the upholder of the Myth of Nature Resilient. It is this rationality, we submit, which comes closest to the answers to these questions.

Let us start, then, by re-labelling this rationality that of the “Adaptor”: the A type. The basic logic of the adaptor’s rationality has been available since the publication of Cultural Theory (1990) and, indeed, back to work in the 1980s. It re-surfaces, in a modestly extended but crucially important form, in Organising and Disorganising (Thompson, 2008a), itself cited in association with the tying up of some loose ends of those strenuous exercises in cross-disciplinary Systems Thinking at the end of Section 4.3. The word there was “grip”, which relates to the exercise of power and influence in the social dynamics of company employee interactions (as observed upon, empirically, in Underwood and Ingram’s (2014) characterisation of the Insurance Cycle). Yet the rationale of the A type has never been employed in practice — at least not self-consciously — with but the single exception of Mitleton-Kelly’s (2004) analysis of Information Systems professionals working in a variety of companies (the type was, of course, referred to there as the hermit).

We are determined — over the long term — to fill this glaring omission, of the stance of what we are now calling the Adaptor, with all its fully intended allusion to the “A” in RA, in rational Adaptation. If we may refer to the collection of the four rationalities of the Maximisers, Managers, Conservators, and Pragmatists as the basic “4”, we would (and should) refer to that of the adaptor as the “special +1”. Further, if that much prized virtue of resilience really matters — that more than lip service may be paid to it — we judge the A type to be the only rationality capable of getting near to delivering it in practice.

Evidence from Practice

Practice, just possibly, may be ahead of theory. For a number of insurance companies, in our experience, are already showing signs of behaving as though they are being guided in some manner by the rudiments of an A type employee.
6 CONCLUSIONS

Our project was sparked by the (2013-17) IFoA study of Model Risk (Aggarwal et al, 2016; Black et al, 2018), significantly in its introduction of the notion of “model culture”. Now completed, we see our present project as having infused that model culture into the (2009-13) Compendium of articles on Rational Adaptability (RA) published in InsuranceERM. But this, we conclude, is not our report’s only achievement. For where RA was previously defined by the theory of Plural Rationality, we judge the social anthropology thereof has in this report been interwoven with ideas inspired by the principles and methods (if not the mathematics) of control theory and feedback control system design.

In retrospect, we are somewhat embarrassed at the (perhaps undue) length of this report. Moreover, we are concerned its main messages may face something of a struggle to reach the light of day, as it were, and there be examined and reviewed. The shortness of this project (four months) may well have deprived us of adequate time for reflection on better means of presenting the detail of our arguments and illuminating its key, essential ideas and findings. In due course, therefore, we intend to produce a (much) shorter article, whose heavily abridged arguments and conclusions can clearly be traced back — for the interested (and determined) reader of such an article, that is — to this present full-length report.
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