THE DILEMMA OF SCIENCE FUNDING – BUILDING UNDERSTANDING WITH SYSTEMS APPROACHES

John Davies, Victoria Management School, Victoria University of Wellington, PO Box 600, Wellington 6006, NZ. john.davies@vuw.ac.nz
Victoria Mabin, Victoria Management School, Victoria University of Wellington, PO Box 600, Wellington 6006, NZ, Vicky.mabin@vuw.ac.nz

ABSTRACT

This paper is one of a series that explores the mutually informing use of alternative systems methodologies and representational tools in building understanding of system-wide dilemmas faced by decision makers. In this paper, we consider the dilemmas faced by those charged with determining the nature of science funding within New Zealand (NZ), and how they are perceived by those wishing to affect, or are affected by, funding decisions. The paper provides a constructive illustration of how the Causal Loop Diagrams of System Dynamics and the Shifting the Burden archetype can be used in complementary fashion with TOC tools to suggest new ways for approaching such dilemmas.

INTRODUCTION & OVERVIEW

This paper is one of a series that complements prior work examining the development of multi-methodology. It does so by exploring the benefits arising from the mutually informing nature of systems methodologies in addressing problematic situations, especially how the use of one methodology may mutually inform the use of the other, and how insights derived from one methodology can mutually inform the development of insights from the other [1] [2] [3] [4]. Here we seek to demonstrate how the conflict or dilemma resolution process of the systems methodology known as the Theory of Constraints (TOC) can be used to complement the use of traditional systems approaches involving Causal Loop Diagramming (CLD) and System Dynamics (SD) [5]. Our demonstration is facilitated through a multi-method examination of an illustrative case which refers to what we will refer to as the science system, with particular reference to dilemmas currently existing within the science funding system in New Zealand (NZ). We first provide a brief background to the science system and the science funding system, and position the case by outlining views expressed by significant players in the system. We note that it is characteristic of a dilemma that different parties have diverse views of the same problematic situation - undesirable symptoms and effects etc - and seemingly irreconcilable opinions of how they should be addressed. In this paper, in illustration of our approach to understanding such situations, we first seek to capture and portray such alternative or conflicting views of a dilemma, and any embedded cause-effect (C-E) relationships, using the CLDs. In doing so, we foreshadow that our first, and plausible, CLD representation does not capture or reflect the objective of the system. We then seek to demonstrate how the conflict representation and resolution process of TOC can enhance understanding of the problem by surfacing the system's overall goal, and by making explicit alternative actions that are believed to be necessary to achieve the objectives. Finally, we show how, by incorporating the system's goal, the C-E relationships and alternatives in an extended CLD, we can provide an enhanced representation of the dilemma, and a more appropriate platform for decision making.

BACKGROUND TO THE NEW ZEALAND SCIENCE SYSTEM

Change and Reforms since the 80s

This paper presents a view of science reforms in NZ over the last two decades, but situates them in the changing political contexts of the science system and wider reforms underpinned by fiscal concerns about the need for more effective use of the public purse in the national interest, and by views about the need for improved governance and accountability within the public sector. They also included, for example, the ideological opening up of markets to competition through financial deregulation, the removal of state subsidies and sector-protecting import tariffs, and the corporatisation or privatisation of state-owned assets and enterprises. The reforms were designed to impact on governance processes especially in ministries and government departments, creating a clear separation of political policy decisions from departmental policy development, analysis and advice, and from service delivery in the state agencies; clarifying managerial and operational responsibilities, and strengthening accountability and control mechanisms that relate to outputs and outcomes rather than processes. General issues posed by the very nature and subsequent impact of the wider reforms on public sector management and managerial practice have been documented elsewhere (see Norman [6] [7] [8]). The articulation of these wider reforms first translated to the research sector in the form of discussion reports in the mid eighties [9] [10] [11]. At that time, the predominantly state-funded discipline-based science system was guided and administered by the National Research Advisory Committee (established 1963, disestablished 1986); universities were separately block funded for research; and several government departments self-funded their own research units. In addition, a Social Science Research Fund Committee distributed research grants mainly within universities. We also note the impact of the 1989 Public Finance Act [12] [13] on the financial management of the Department of Scientific and Industrial Research (DSIR) and other government departments. [14]. The Beattie Report resulted in the formation, in 1987, of a senior cabinet committee, the Science and Technology Advisory Committee (STAC), to advise government on science policy. STAC's deliberations led to the establishment in 1990 of the Ministry of Research, Science and Technology (MoRST), which was given the responsibility for developing science policy, and, in 1991, the Foundation for Research, Science and Technology (FRST), constitutionally independent of MoRST, and with responsibility for implementing policy, including the administration and allocation of research funding, and the monitoring of research performance related to that funding. Recommendations from STAC [15] [16] led to the 1992 restructuring of what we may call the science provider sector. STAC's recommendations impacted mainly and directly on the government-funded DSIR, resulting in its dissolution, and that of a smaller number of other government research departments and agencies, and then their replacement by ten Crown Research Institutes (CRIs), to operate in different sector-based domains as quasi-independent "science-providing companies." The CRIs were free to contract with private sector organisations, but given a requirement to return a profit to their primary stakeholder, the government. The STAC *New Deal* report [17] also recommended a change from block funding of research agencies to bids for contestable funding for specific project proposals. The funding pool, euphemistically labelled the Public Good Science Fund (PGSF), was to be administered by FRST, and funding for projects would be determined by peer-reviewed assessment of relevance of stated outputs to government-determined science priorities, anticipated costs and benefits, and perceived quality of proposals. The Minister of RST stated that purchasing science outputs on a contestable basis through PGSF would give "a stronger strategic direction to the government's investment in science and technology," and induce a needed "client focus within science organisations" [17]. One (unwitting) consequence of the bidding/funding process was manifest as a *de facto* switch in budgetary control from the research agencies to central government; another represented a change to government determination of science priorities for the PGSF, albeit through a government appointed

Science and Technology Expert Panel (STEP) [18]. A third consequence was that the annual bids for funding were soon recognised as generating considerable transaction costs and unnecessary uncertainty for medium/long term projects and for the science provider[16]. Other undesirable effects of the new system [16], based on interviews with science providers and surveys conducted by the Association of Scientists[19], related to the lengthy and intensive bidding process that led to managers and top scientists being overworked, and long lead times before decisions on funding were made available. It has been claimed [16] that such a process led science providers to favour 'safe science' and that the system *de facto* limited funds for the technology transfer which was necessary to turn science into practical reality. It has also been claimed that the changes had a demoralising effect on the science providers with many of them perceiving their ability to produce quality science as being diminished or eroded. By 1995, and in response to the latter concerns, FRST introduced a bi-annual bidding round [20]. The government had also accepted broad recommendations emerging from the sectoral Science Strategy Committees. These recommendations were translated into PGSF priorities for the period up to 2001, broken down to seventeen 'output classes' and then linked to detailed FRST determined research strategies for each class [21]. Cartner and Bollinger [22], in discussion of these and prior science reforms, have commented, perhaps with some surprise, that even the most radical reforms in the eighties were noted for the "lack of public controversy", despite basic tensions within and arising from the reform models-in-use. They partly attribute this to the "political successes achieved by the science lobby" in consolidating public funding; to the politicisation of research objectives; and to the consequent privileging of research agenda relating to such objectives – perhaps implying that what others have referred to as "science capture" had ensured that the "reforms" were palatable. However, this positive interpretation of a pro-active science sector was not shared by others [16] who believe that subsequent and erstwhile reforms may have been affected by advocacy from the science sector [23] [24] - but only as a necessary reaction to perceived increasing competition from universities for additional research funding.

Proposed Science Reforms - 2006

For our discussion of the current situation, we move forward to a science system which can be said to be radically different to that of twenty years ago when the first major public sector reforms were contemplated. Indeed, Davenport and Leitch [25] have commented that the science sector has been impacted by the raft of public sector reforms perhaps more than any other sector. The science funding system has also evolved [16] [28] [26], refining its 'incentives' for how research should be conducted and what its content should be. The NZ research sector is also more diverse, and though more of NZ's researchers now work in universities, many work in the CRIs that replaced the DSIR and other research providers. However, we may also note that whilst initiatives have been put in place specifically to support NZ universities, that CRIs have been required to operate as businesses, a requirement not expected of universities or of similar organisations in other countries; and that a severely constrained total budget for science has been associated with a *de facto* shrinking fund for the CRIs. Underpinning recent considerations of further reform, we note the ministerial view [27] that recognising and making the link between research excellence and the funding for research (via the Performance Based Research Fund (PBRF) process introduced by the Tertiary Education Commission (TEC) in 2003) was, and has been, necessary, as was the need for government to encourage and match private sector investment in universities. In May 2006, Maharey stated [33], prior to the budget, that Cabinet proposals would "provide greater certainty of funding for programmes with a proven track-record." He reasoned that while contestability would continue to be an important part of the science system, "too much contestability can affect the ability of our scientists and science organisations to carry out research and apply their ideas over a longer period." He added that the proposals aim to put greater trust in scientists and science organisations, and will mean “more consistent support for long term research” and a “reduction in the costs and complexity of the funding system.”

Funding of Science Proposals – Budget, May 2006 [28].
Introducing negotiated investments for longer-term programmes with a proven track record
Systematic assessment of scientific quality, **fit with national priorities**, and **delivery of outcomes**
Steps to reduce cost and complexity of competitive funding processes - which remain the most appropriate mechanism for many science investments **Identify ways to provide more certainty of funding** for essential 'backbone' infrastructure, such as nationally significant databases
Continuing to increase the capability of NZ's Crown Research Institutes

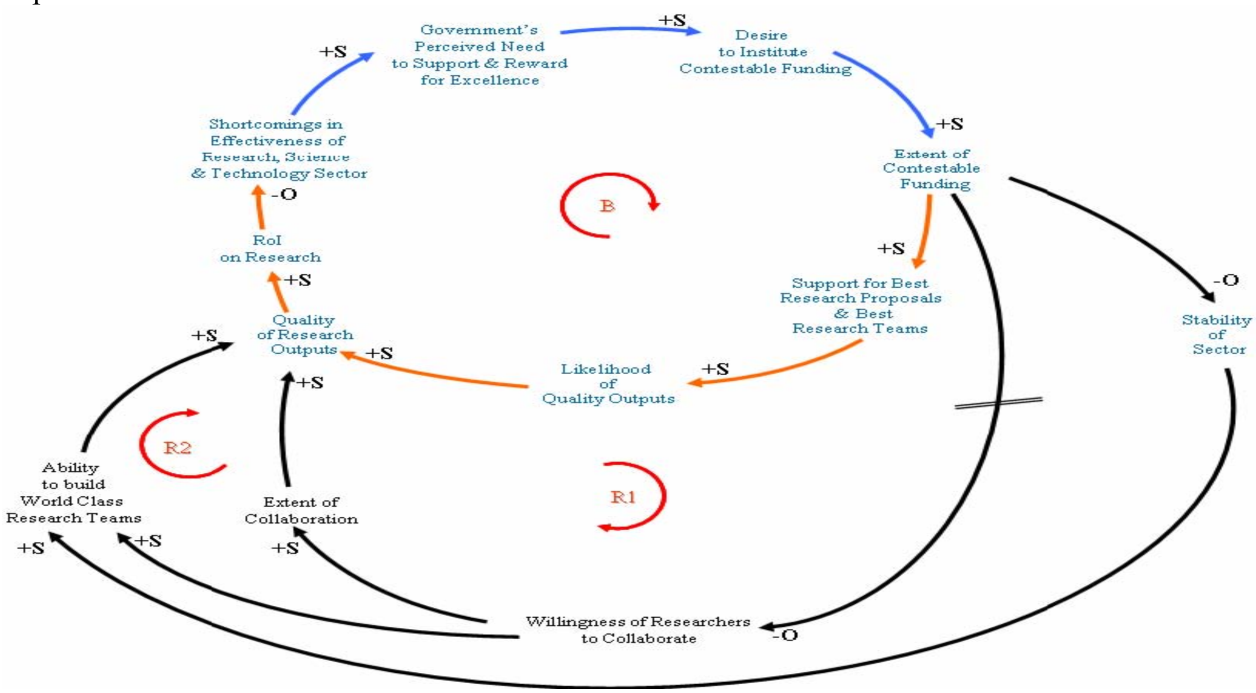
The Emerging Dilemma - Contestable or Negotiated Funding

As those in the research sector took stock of the budget proposals, divergent views emerged of how appropriate the government’s initiatives were. Here, we present the views of those in the different sectors, in order to provide a context for the remainder of the paper. We mention, the remarks of Education correspondent, John Gerritson [29], that the budget proposals “would see less of the NZ$633m per year in government RST funding available on a purely contestable basis” and would include a shift in emphasis for assessment of research proposals to “direct rather than possible outputs.” However, it was the view of NZ Vice-Chancellors (V-C) Committee deputy chair, Auckland V-C Stuart McCutcheon, that the government had been unable to produce any proof other than anecdotal that the science sector would be better off if the distribution of funding was less competitive. McCutcheon said universities and research associations had been increasing their share of RST funding, and he could only conclude that the proposed funding changes were aimed at reducing the ability of those organisations to bid successfully. The Treasury view was that negotiated re-investment could lead to inertia, with projects continuing to receive funding simply because it may not be clear what the impacts would be if funding would cease., and that there was no clear evidence that the problems associated with the current funding system were of major consequence or systemic. But in putting the changes to Cabinet, Maharey’s contrary view was that the continuation of successful research programmes was frequently put at risk by the contestable system. Maharey believed that “an over reliance on competitive bidding processes” had negatively impacted on maintaining capabilities required in the longer-term; on evaluating the performance of research programmes; and on the career development and retention of scientists and technologists. However, Neil Quigley [30] PV-C (Research) at Victoria University, aligned his view with McCutcheon, claiming that competition is “vital for science funding.”
Quigley stated that to ensure the best return to an annual investment of $750m in scientific research, the allocation need to rely to a considerable extent on competitive bids, and on rigorous assessment of those bids. He claimed that the share of competitively allocated funds won by universities had increased because they had “consistently written the best research proposals and produced research of the best quality.” Quigley asserted that the CRIs had lobbyed for changes to funding mechanisms to protect and enhance their share of research revenue. Andy West, CEO HortResearch CRI, offered a counter view that competition biases the funding system against the CRIs inducing perverse outcomes such as a lack of collaboration and loss of world-class scientific capability. Our representation and analysis of seemingly divergent views of those in the University and CRI sectors follows in subsequent sections. So far, we have simply set out a selection of views to illustrate an emerging dilemma and provide a context for the remainder of the paper – rather than critiquing such views. .

BUILDING A MULTIMETHODOLOGICAL APPROACH

The Initial Causal Loop Diagram

We note that the CLD in Figure 1 displays how extending contestable funding in response to perceived shortcomings in the effectiveness of the RST sector has impact beyond that which may have been expected.



Note that CLD convention requires entities to be described in neutral mode. The +^{ve} **S** and –^{ve} **O** annotations then allow relationships to be described in the context of starting or changing conditions. The +^{ve} **S** annotation indicates that the *more* we do the action at the tail of the arrow, the *more* the effect at the head of the arrow. For example, the *more* we have X, the *more* Y is needed. By contrast, the –^{ve} **O** annotation indicates that the *more* we do something, the *less* the effect. The double bar // across an arrow denotes a delay – the effect will occur over time or after a time.

In particular, we see that whilst extending contestable funding may have its desired and intended impact in the short term (see balancing loop B), it may also have unintended and unwanted effects on the willingness of researchers in competitive situations to share ideas and collaborate in a manner that is considered necessary to improve the quality of research outputs. As a consequence, contestable funding may lead to a worsening of the quality of research outputs (as indicated by the reinforcing loops R1 & R2), thus reducing those perceived shortcomings. We thus note how our CLD structure can be identified as a modified version of Senge's *Fixes that Fail* archetype – the *Quick Fix* making the problem worse in the longer term [31] [32] [33], but that no alternatives to a *Quick Fix* have been captured by the CLD. We will now show how TOC's conflict resolution process can help identify and structure a dilemma using the EC framework of Goldratt [34] [35] [36] [37].

The Theory of Constraints - Evaporating Cloud (EC)/Conflict Resolution Diagram (CRD)

TOC as an espoused methodology seeks to assist with the 'management of beneficial change' in organisations. In many cases, such change relates to the resolution of dilemmas. For our situation, and for the illustration captured as Figure 2, we note how the dilemma has been framed as whether Government should extend contestable funding in the Research sector or institute what it terms “negotiated institutional funding.” Using the EC framework allows one to draws explicit attention towards the choice dilemma, the overall system goal, and also the assumptions that underpin or give life to the dilemma. The reason for conflict can be explored by examining the assumptions that underlie the necessity-based logic relationships, depicted here by arrows connecting the boxes in the diagram. The EC frames the problem starting with what is believed to be two diametrically opposed actions or views (represented in boxes D & D'), and implicitly assumes these can be resolved by a win-win solution.

FIGURE 2 -TOC EVAPORATING CLOUD FOR THE SCIENCE FUNDING CASE

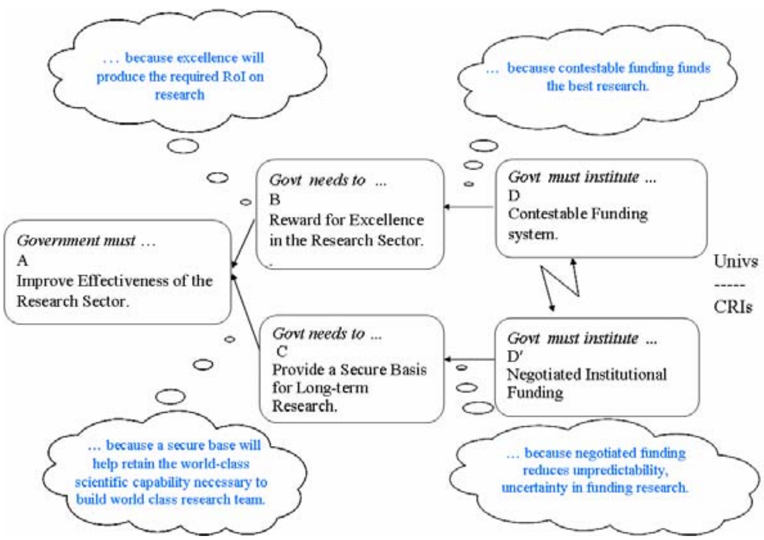


Figure 2 suggests that the dilemma can be interpreted as follows:
… that **in order** to ensure objective A the improvement of research sector effectiveness, the **Government must** B improve support and reward for excellence in the Research sector …
… and **in order to** B improve support and reward for excellence in the Research sector, the **Government must** D institute negotiated institutional funding.
On the other hand, we also need that:
… that **in order** to ensure objective A the improvement of research sector effectiveness, the **Government must** also C provide a secure basis for long-term research …
… and, **in order** to C provide a secure basis for long-term research, the **Government must** D’ institute negotiated institutional funding. Hence the conflict!

In order to find a solution, we elicit those assumptions, perceptions or beliefs why the relationships are thought to hold, seeking to provide a substantive rationale for the existence of the relationships or of intermediate links.

The Second Causal Loop Diagram

We need to state that the purpose of the CLD is to build an effective representation and better understanding of the dilemma that may lead to its resolution. By contrast, the purpose of the EC is to resolve the dilemma [38]. Although the EC process does require the overall objective of dilemma resolution to be specified, the EC diagram only represents the necessity logic underpinning the relationships. Additionally, what we regard as a "long link" in the EC creates and reflects a need for the presumed logic to be supported by accompanying assumptions, reasons etc - shown in Figure 2 as thought bubbles. This process not only helps to explain the dilemma, but also to enable the problem owners to generate one or more win-win solutions. In a similar way, we often note the existence of long links within CLD representations, and then, for these representations, interpretation of the CLD will also depend on assumed or implicit logic, and explanation through accompanying narrative. It is important to note that whilst a CLD seeks to reflect a holistic view, it can not hope to show all necessary and sufficient logic for all relationships. In examining the nature of properties that underpin our ability to translate from the EC to CLD, we need to be mindful of the subtle differences in the nature and representation of the logic – especially how the assumptions "underpinning" a relationship between entities in the EC will often be intermediate links in

the CLD logical chain. For example, we note for one branch (A-B-D) of the EC, the necessary logic expressed as:

In order to have A, we *must* B improve support and reward for excellence in the research sector, *because* AB excellence will produce the required RoI in research…
can be reframed in the CLD as … the objective A *influences* B the **need** to improve support and reward for excellence in the research sector ….

However, we note that the assumption AB requires us to somehow create the effect **β** the required RoI. Similarly, we note for the same branch of the EC, the logic expressed as:

In order to have B, we *must have* D, *because* BD contestable funding identifies and funds the best research and the best research teams …
can be reframed in the CLD as … the B need to improve support and reward for excellence *influences* the action D extending contestability and competitive bidding.

Additionally, we note that the assumption BD requires us to acknowledge that contestability creates the effect **δ** the funding of the best research and the best research teams.
Bringing these notions together in the CLD, we have …

… the objective A *influences* the need B to improve support and reward for excellence, which *influences* the action D instituting and extending contestable funding, which *influences* the effect **δ** the funding of the best research and the best research teams *influences* the effect **β** achieving the required RoI on research *influences* objective A.

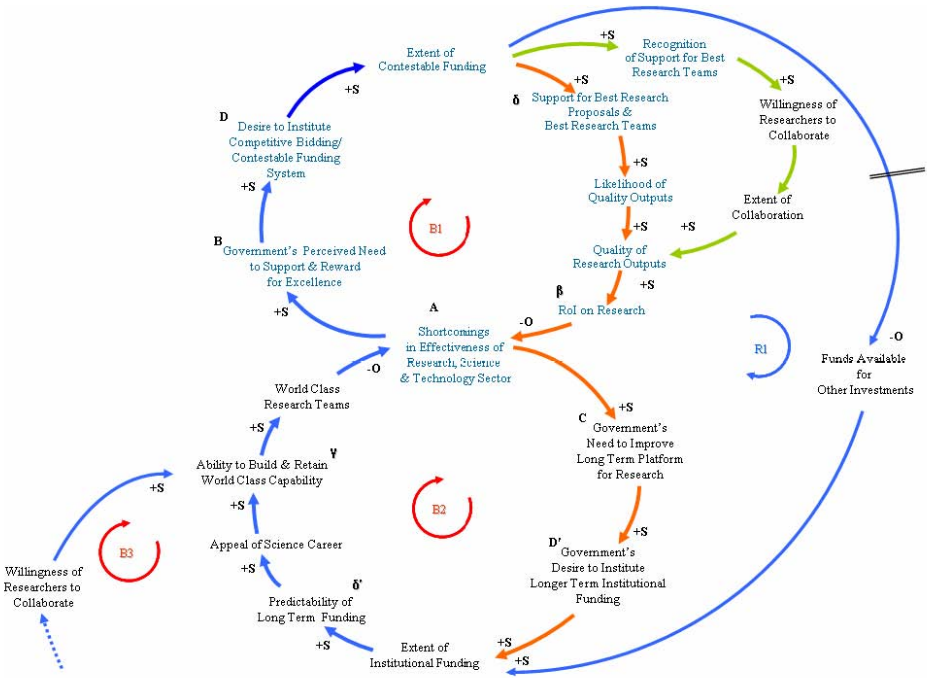
In summary, our CLD represents:

… the objective A *influences* the need B *influences* the action D *influences* the effect **δ** *influences* the effect **β** *influences* the objective A. … as Loop B1, and …
… the objective A *influences* C *influences* D′ *influences* **δ′** *influences* **γ** *influences* A … as Loop B2

Our second CLD builds on the first, and takes account of the views of the parties in conflict surfaced using the EC, in order to build a more comprehensive understanding of the dilemma facing the government as funders.

Interpreting the loops in our second CLD suggests that the more the Government extends contestability in science funding (Loop B1), the less funds it will have for other ways of investing in science, thus undermining the effectiveness of, say, negotiated institutional funding (B2). Extending this interpretation to our EC, we see that doing more of D jeopardizes the requirement C to improve the long

FIGURE 3 – A 2ND ILLUSTRATIVE CAUSAL LOOP DIAGRAM (CLD) FOR THE SCIENCE FUNDING CASE



term platform for research. Similarly, the greater the Government's use of negotiated institutional funding, the less willing research providers might be to engage in collaborative attempts at seeking contestable funding – that is, D′ threatens or jeopardizes the need B to support and reward excellence by undermining the means to support the best research proposals and best research teams. We note that these systemic effects or emergent properties are redolent of Senge's *Shifting the Burden* (STB) archetype, where the *Quick Fix* undermines our ability to execute an alternative *Fix*. We thus suggest there is promise of being able to transfer understanding from the domain of CLDs to the domain of TOC, especially given that Senge's archetypes provide a basis for recognizing structures embedded within the chronic conflict situations identified by TOC practitioners [39]. However, before accepting the seductive existence of such systemic structure within the CLD, we need to explore or challenge the embedded logic further - and to do so, we can use TOC logic tools, specifically the protocols invoking the Categories of Legitimate Reservation (CLRs), to audit the CLD logic, that is, the C-E thinking. In addition, we must surface and challenge assumptions about whose perceptions are being captured by the CLD, and why. Surfacing such assumptions can raise other questions that may establish or undermine their validity, thus provoking alternative possibilities for solution [40]). Our illustrative analysis and interpretation thus illuminates how the EC and CLD approaches and representations create a dialogue that can be seen to move the debate from arguing about which side is right, to finding a resolution, which is to engage in world class research projects and to build research sector capability.

DISCUSSION AND CONCLUSIONS

We now outline how the various approaches have been applied to the science funding situation, and how insights have emerged from such use, providing improved understanding leading to effective resolution of conflict.

Methodological Insights - The CLD representations of entities and C-E relationships, shown in Figures 1 and 3, are meant to be reflective of the perceived systemic reality of the science funding case. The initial CLD, however, does not explicitly capture any perceived choice other than contestable funding. Nevertheless, it does implicitly present action options for different degrees of contestability, and allows us to map out the systemic consequences and interactions that emerge. Thus, whilst it may be claimed that identification of the core choice dilemma, that is the basis for the EC, may be drawn from the initial CLD, we suggest that constructing the EC demands that we identify the overall system goal and devote attention to other viable alternative actions, all of which can then be mapped to a CLD representation. In this case, the overall goal identified for our illustrative purpose was *improving the effectiveness of the RST sector*. We suggest that iterative and mutually informed construction of EC and CLD diagrams is therefore possible and desirable. Additionally, we note that the assumptions embedded within the EC, and supporting the EC logic, can surface as intermediate entities - causes and effects - within a more comprehensive CLD. Similarly, entities introduced to the CLD for clarity, and to aid comprehension, can also be usefully incorporated into the EC, forming part of the underpinning logic as intermediate actions or as explicit assumptions. We foresee benefits in using CLD representations to better diagnose and understand the nature of chronic conflict captured in EC representations, and to better understand how and why the taking of any one action can undermine our ability to enact an alternative, when both are necessary requirements for the overall objective. Such understanding is necessary to build lasting solutions when confronted by dilemma or conflict.

Problem Insights - In keeping with their purpose [44], the CLDs, shown in Figures 1 and 3, reveal the prior implicit interconnectedness of variables. Indeed, the CLDs help build an understanding of what we regard as the systemic nature of the relationships. The CLDs not only highlight the dynamic time-based nature of feedback, the existence of balancing (B) and reinforcing (R) feedback loops, delays and side-effects; but also help distinguish between "individual" Government or science provider behaviour and systems behavior, between seemingly predictable individual behavior and local outcomes, and the systems behavior that may be expressed as the unpredictable or unanticipated "emergent" properties of the system. Additionally, the CLD may help us recognise how individual or system behavior can lead to unintended, unanticipated, unwanted, yet often patterned and predictable outcomes. Here, for example, we note how the introduction of contestable funding may seemingly reduce shortcomings in research sector effectiveness in the short term, as shown in loop B1 in Figure 3. However, the sequence of behaviors and effects, that play out in the longer term, creates an extended feedback loop R1 that will undermine the research sector's ability to build a strong long term platform for research in the CRIs, thus undermining the conditions necessary for the success of the negotiated funding alternative. In conclusion, we suggest therefore that the insights that arise from our use of mutual informing methodologies help build understanding of the inherent conflicts embedded in alternative approaches, an understanding that is necessary for the effective management of the science funding system. .

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A full list of references may be obtained from the authors on request.