Is the commercial model appropriate for science?

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Introduction

Government-funded science in New Zealand has undergone major reforms in the last 15 years. Until 1985 most government scientists were employed as public servants in a number of government departments, the largest being the Department of Scientific and Industrial Research (DSIR) and the Research Division of Ministry of Agriculture and Fisheries (MAF). In 1985 the Government introduced policies which required that these government departments become more commercial—that is to say government funding was capped and they were urged to raise revenue by marketing and selling their products and services to the public, and particularly, to the major industries. This policy was referred to simply as 'user pays'. This applied similarly to University science although their source of funding was through different government agencies.

This move toward the commercialisation of science was formalised with the passing and implementation of the Crown Research Institute Act 1992. Government-funded science was now configured into ten (subsequently reduced to nine) Crown Research Institutes (CRIs), each aligned to different sectors of the economy: four related to primary industry; two aligned to secondary industry, and a further three to the nation's natural resources (see Goldfinch & Bellamy 2001). While the primary purpose of the CRIs was essentially the same as it had been for the Government departments—namely to undertake research for the benefit of New Zealand—they were now to be operated and managed as commercial entities, including the requirement that they generate 'an adequate rate of return on shareholders funds', the shareholders in this case being the Minister of Finance and one other Minister of the Crown.

The CRIs have now been in operation for a decade, and information is now emerging on their performance. For example, in their 10-year review, the Ministry of Research, Science and Technology (MoRST 2002) concluded that, 'There is no doubt that the last ten years have been successful ones for CRIs.' ~~This positive view is not, however, shared~~ by CRI scientists, who in a recent surveys (Sommer & Sommer 1997; Sommer 2001) indicated a significant degree of dissatisfaction with their new commercial environment. Furthermore, two policy analysts, who worked in the reformed science system (Devine 2003; Winsley 2003), have identified problems with the reformed model and suggested significant changes.

The OECD (2003) has recently assessed the worldwide challenges facing publicly-funded science, and their report focuses on the external structures and policies that have variously been developed within OECD countries in response to these challenges. Notably New Zealand was not represented on the ad hoc committee which undertook this study, and, it appears, is the only OECD country which has adopted a fully commercial model for its public science institutions.

The focus of this paper is not the external requirements of modern science, including the difficult issue of the allocation of science funds. Rather it is concerned with the essential values—those qualities essential for its purpose and conduct—required within a science organisation that best represent, preserve, and serve the interests of science and therefore the public. In so doing, it attempts to answer the question: Is the commercial model appropriate for science?

Need for reorganisation

The motivation for a change in the New Zealand science environment, at its most basic level, was expressed in the terms of reference for their Ministerial Working Party on Science and Technology entitled *Key to Prosperity: Science and Technology* (Beattie et al. 1986): 'Our national development has come to something of a hiatus. There are serious difficulties with traditional export products and there is an urgent need for innovations, in the processing of traditional commodities for the development of new possibilities, and in marketing.'

In their report they document the available economic studies showing the positive net benefit of investment, both private and public, in research and development (R&D) in terms of knowledge, innovation, and productivity, and hence, in society as a whole. Based on this principle they noted three essential components which must be improved if New Zealand was to follow the '... well-established trend of many other developed countries towards dependence on knowledge-based rather than labour-based industries ...' These were:

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1. An appropriate investment in R&D in both the public and private sector. (In fact they recommended doubling of the 1986 public expenditure by 1993–99.)
2. An adequately trained and informed work force.
3. A confident awareness on the part of managers and boardrooms of the potential of R&D to facilitate innovation in their particular areas.

They concluded that, 'We are convinced that New Zealand's overall present performance in all three aspects is less than adequate to achieve a significant rate of real growth. Market forces cannot be expected, unaided, to influence these important factors sufficiently to allow New Zealand to hold its own against competition, let alone do better'.

Specifically, Beattie et al. (1986) accepted the principle of user pays and that 'the beneficiaries of particular research should be identified wherever possible and expected to pay'. However, they noted that the principles of the market philosophy, when applied to science, can fail and concluded, 'For these reasons, a significant part of a country's wider research and development has to be recognised by the government as a public good and be supported by public funds'.

The working party recommended the establishment of a Minister of Science and Technology, a Cabinet Committee on Science and Technology, and a Science and Technology Advisory Board to respectively: enhance the profile of science and technology; develop science policy; and advise the government on R&D issues. At the science management level, the establishment of a Science and Technology Council was recommended, whose responsibility was to allocate and fund basic and applied research through the existing government departments, universities, and Research Associations.

The Beattie Report was ignored by the government, who responded by establishing another committee to review science and technology. Their report *Science and Technology Review: A New Deal* (Arbuckle et al. 1988) noted that, 'A reason for the luke-warm reception which the report of the Beattie Committee encountered from some officials was the fact that Beattie relied on simplistic assertions of market failure as a justification for government funding'.

The *New Deal* signalled a radical shift in science policy and management. Many reasons were advanced to rationalise these changes including: the need to improve allocative efficiency; shifting management responsibility from inputs (i.e. expenditure) to outputs (specified outputs and outcomes); and, somewhat ironically, overcoming the confusion that had arisen, particularly among the science community, regarding the user pays policy.

More profound, in terms of their subsequent effect on science, were the recommendations to adopt a policy to, '... give government R&D institutions access to a full range of commercial powers', and, '... adopt contestability as the governing principle for the allocation of funds for research and development activity'. The reason for the former recommendation was not simply to overcome the management restriction implicit in the Public Finance Act, such as its emphasis on measuring expenditure rather than output or outcomes, but also to enable government research institutions to engage in the many forms of contractual arrangements possible in the commercial sector. This, it was argued, was essential to encourage private investment into science and technology.

The principle of establishing one large contestable pool of government funds, to replace the former system of government department allocations, was simply the application of market theory to the science sector—the market, not the government, would provide the best signal as to how to allocate R&D expenditure (see Boston et al. 1998 for a formal discussion of this principle). To support this recommendation, the Arbuckle Report strenuously countered the market failure arguments offered in the Beattie Report and argued the case that the government should not, unless under very specific and narrow conditions, intervene in the market place. This appropriability argument is, as noted by Devine (2003), a 'Catch 22'. The position taken in the Arbuckle Report was in essence: if there was someone who benefits from the research then they, not the government, should pay for it, leaving the crown to presumably fund research for which no-one benefits! At its extreme, the Arbuckle Report argued the case for the government not funding R&D — quite a different policy position from that reached in the earlier Beattie Report.

The new structures

As a consequence of these reports, and applying the policy/funder/provider split philosophy, the government established two new organisations: the Ministry of Research Science and Technology (MoRST), to develop policy and advise the new Minister of Science and Technology; and the Foundation for Research, Science and Technology (FRST), whose role was to implement government policy, particularly as it related to the allocation of funds within and between the CRIs. In this sense, the recommendations of both the Beattie and Arbuckle Reports were accepted in principle.

Funds previously allocated for R&D to various government departments were consolidated into a single contestable pool, and scientists or groups of scientists applied for funds to undertake research the output of which was consistent with desired and broadly specified government outcomes. If the application was accepted, a contract to deliver the specified output was signed. This was typical of the application of contract (or agency) theory across the public services (see Boston et al. 1998 for a discussion of this).

As noted above, nine CRIs were established under the Crown Research Institutes Act 1992. Consistent with the recommendation of the Arbuckle Report that government R&D have a full range of commercial powers, these were commercial organisations owned by the government. As defined by their empowering Act, 'The purpose of every Crown Research Institute is to undertake research'. The Act also sets their principles of operation, which include, in part, the following:

> *Every Crown Research Institute shall, in fulfilling its purpose, operate in accordance to the following principles:*
>
> > *That research undertaken by a Crown Research Institute should be undertaken for the benefit of New Zealand;*
> >
> > *That a Crown Research Institute should promote and facilitate the application of (i) the results of research: and (ii) technological developments.*

Every Crown Research Institute shall, in fulfilling its purpose, operate in a financially responsible manner so that it maintains financial viability.

A Crown Research Institute is financially viable if: (a) regardless of whether or not it is required to pay dividends to the Crown, the activities of the Crown Research Institute generate, on the basis of accepted accounting principles, an adequate rate of return on the shareholders funds; and (b) The Crown Research Institute is operating as a successful going concern.

It is useful to compare this legislation with that which it replaced. The largest government research department at the time of the reforms was the Department of Scientific and Industrial Research (DSIR). Its primary functions as set out in the DSIR Act 1974 were (section 5a), 'To initiate, plan and implement research calculated to promote the national interest of New Zealand' and (section 5d), 'To collect and disseminate scientific and technological information, including the publication of scientific reports and journals'. The Research Division of the Ministry of Agriculture and Fisheries (MAF) was similarly charged to undertake scientific research and extension activities, albeit in the specific area of agriculture, as set out in the MAF Act (1953).

In one sense then, the purpose of the new CRIs was no different from the organisations they replaced—they were charged with the responsibility of undertaking research for the good of the nation. However, in addition, they were required to operate as commercial entities under the Companies Act. This required 'an adequate rate of return on the shareholders funds'. In short, they were required to make a financial profit.

Surprisingly, prior to the implementation of these reforms, there was no formal analysis and discussion as to whether the commercial model was appropriate for science. As recorded by Devine (2003), 'they were undertaken within a one-dimensional "market-solves-all" framework', in the expectation that this would result in a better alignment between research and end-users and greater transparency, accountability, and efficiency. In other words, it was simply assumed that the only alternative to the public service model was the commercial model.

Organisational models

Mintzberg (1996) has defined four types of organisational models based on their ownership (Table 1) and five types based on their values—the qualities that are essential within the organisation to deliver the intended goods and/or services (Table 2). These organisational types can be considered as a 4 × 5 array (Figure 1), and it appears that most organisations lie along an axis defined by the machine-like, large, profit-driven corporations, at one extreme, and the state-owned normative organisations, such as health and education, at the other. This general trend implies that organisational types have not evolved in a random manner, but according to some important principles related to ownership and values. It appears that organisational ownership becomes more public as the emphasis on the profit motive gives way to other organisational goals. This trend also parallels a shift on the 'goods and services continuum' from largely goods, provided by commercial enterprises, to largely services, with a large human component, in public organisations. Note that this also coincides with the trend from unskilled, semi-skilled and skilled employees to increasingly qualified, trained and experienced personnel.

Depending on how these definitions are applied, there may be some exceptions. The Inland Revenue Department can be defined as a machine-like organisation, based on the managerial requirement for control over personnel, rules and procedures so that tax gathering is fair and equitable to all citizens. It could equally be argued that this organisation is normative, because its purpose is to apply and maintain value of and belief in a fair and equitable tax system. This applies the test of 'normative', not to predominant management activity of the organisation but to the effect of its activity. Another exceptional example is the Consumers' Institute. This is clearly a normative organisation because its purpose and activity is to maintain standards in the manufacture and marketing of goods and services, but it is a non-owned trust. Similarly, the position of SOEs in Fig. 1 depends on whether the tests of ownership and values are applied to the management of the organisation by the owner or the management of the employees within the organisation.

Putting aside these difficulties and exceptions, if there is an empirical relationship between organisational ownership and

Table 1: Four types of organisational models based on ownership (after Mintzberg 1996).

Characteristic	Ownership			
Private	*Cooperative*	*Non-owned*	*State-owned*	
Ownership	private, shareholders	shareholders (limited)	stakeholders	citizens
Motivation & purpose	profit & individual optimisation →		service →	equity, social & moral justice
Operational values	secrecy, confidentiality →			openness, impartial
Competition	essential →			non-essential
Inputs	manual labour, physical resources (tangibles) →			professional skills human resources (intangibles)
Output	private goods (tangibles) →			public goods (intangibles)
Clients	customers →			citizens
Clients' rights & responsibilities	consumer law caveat emptor →			crown law

Table 2: Five types of organisational models based on values (Mintzberg 1996).

TYPE	MOTTO[1]	VALUES[2]
Machine (e.g. Inland Revenue Dept) (large Corporations)	control, control, control	conformity, profit
Performance[3] (e.g. most commercial businesses)	isolate, assign, measure	responsibility, measurement
Virtual (e.g. SOEs)	privatise, negotiate, contract	independence, individualistic
Network (e.g. Foreign Affairs)	connect, communicate, collaborate	relationships
Normative (e.g. Health, Education)	select, socialise, judge	public service, experience, standards, dedication

[1] This is best understood as the prevailing action/activity of senior management
[2] These are the predominant values of the employees
[3] The use of the term performance does not imply that employees in other organisations are not performance orientated.

values, it has important implications in respect to the perennial argument of public versus private ownership, for it suggests that it is entirely appropriate to privatise some human activities. Take for example postal services and telecommunications. The quality of these services focus on price, availability and efficiency. These services are enhanced by being privatised for these are the essential properties – values - of a commercial service. In other words, privatising these activities does not compromise the inherent values in the service.

Conversely, the ownership-value relationship suggest that some human activities should not be privatised, particularly those embodied in normative organisations. The reason for this is that the need for a return on investment, and all that follows from this, can compromise the values and beliefs required to deliver the intended service. It is, given this analysis, no surprise that attempts to commercial health and education in New Zealand have failed.

Where does science fit?

In the context of this 4 × 5 organisational model, the reforms have moved New Zealand's government-funded science from a normative organisation into a performance-based organisation, managed by measurement, particularly financial measurements. What, if any, are the implications of this change? To answer this question it is first necessary to attempt to define what science is and then proceed to develop a minimum set of conditions required for its conduct.

At its essence, science is a tool, a process, a set of implicit rules that can be applied to phenomena in the pursuit of understanding and ultimately discovering a 'truth'. The process requires a commitment to the values of objectivity, impartiality and honesty. These standards are maintained by a commitment to freedom of thought and openness to scrutiny and debate. This is achieved by peer review. It requires people who are

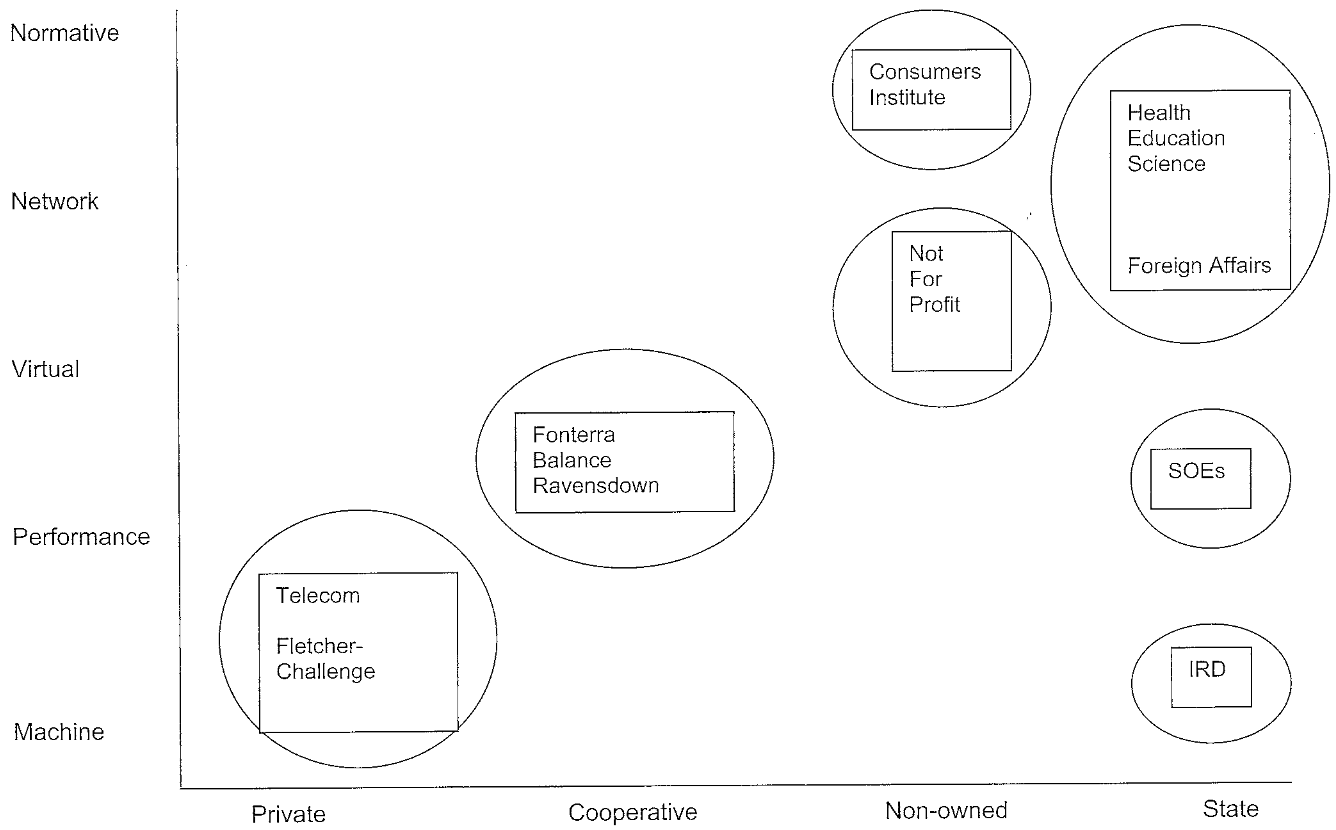

Figure 1: The 5 x 4 ownership:value matrix.

suitably trained and experienced and who are committed to values that the discipline of science requires.

Ziman (1994) has defined some of the necessary conditions for science to flourish as follows: 'Any research [science] organization requires generous measure of the following: a) social space for personal initiative and creativity b) time for ideas to grow to maturity, c) openness to debate and criticism, d) hospitality towards novelty and e) respect for specialised expertise'. These very general requirements emphasise that science is a creative, human activity. Devine (2003) takes this further when discussing the role of science in economic development: 'Human capital, embodied in the people with the skills and 'knowhow' is the key to economic development'. The key resource then, in any science organisation, is the human resource—the pool of suitably trained and experienced scientists—not bricks and mortar, typically the major resource in a commercial operation.

These requirements suggest that the optimal organisational model for science is normative (Table 2) and, using Mintzberg's (1996) criteria, the characteristics of science and commerce can be compared (Table 3). What becomes obvious is that the characteristics of a normative science organisation are very different from those of a commercial performance-based organisation. In fact, in many of the defining characteristics, science and commerce appear to be mutually exclusive.

Table 3: Some characteristics of Science and Commerce.

Property	Science	Commerce
Motivation & purpose	***Truth & understanding*** Help/save/solve Public optimisation Health and wellbeing	***Profit*** Private optimisation Distribution of goods Employment
Operating values	Openness Debate/discussion Peer review Publication Impartial, objective Independent	Confidentiality Non-disclosure Non-publish Secrecy Corporate
Competition	Not competitive Networked Collaborative	Competitive Them v. us Isolationist
Inputs	Trained/skilled Human resource Experience	Bricks & mortar Capital Unskilled labour
Outputs	Knowledge Understanding Solutions Human welfare	Profit Patents Trademarks Copyright
Clients	Taxpayer	Customer
Clients rights & responsibilities	Citizens rights	Consumer rights

Predictable consequences?

If this organisational model is correct, it is predictable that applying the performance-based commercial model to publicly-funded science organisations will lead to conflicts particularly in respect to: (a) the independence and objectivity of science (profit motive v. the national interest), (b) accountability (public v. private good) (c) measurement (financial v. non-financial performance) and as a consequence (d) human resources (service to science or the company). Other questions also arise: What are the implications of applying contract theory and contestability to science?

The Crown Company Monitoring Advisory Unit (CCMAU) (CCMAU 2002) reported to the incoming government that the CRIs, since their establishment in 1992, have: increased total operating revenue by $146m (44%), increased net profit after tax to $23.3m, achieved an aggregate return on equity of 7.5%, paid dividends of $13.3m and tax of $64.5m, and grown shareholder equity from $156.1m to $320.8m and total assets from $257.6m to $441.0m. CCMAU concluded that, 'The organisations now exhibit a stronger and more pervasive strategic focus and have greater performance expectations than the departments from which they were formed. They are also broadening their revenue base and are becoming much more market focused. Consequently the CRIs are much stronger organisations than at the time of their establishment'. Similarly, MoRST (2002) were flattering in their assessment of the performance of the CRIs over the first 10 years, claiming that they 'have achieved outstanding financial success ...' and that, 'The CRI structure has benefited CRIs in terms of focussed research effort, improved research conditions and enhanced innovative capacity'. Note that such measurements are the typical performance measurements for a commercial performance-based organisation.

In stark contrast, a survey of New Zealand scientists and technologists was undertaken in 1996 and again in 2000 (Sommer & Sommer 1997, Sommer 2002). While the authors noted some hopeful signs, they reported that, '... these hopeful signs are countered by others which indicate a stunning level of dissatisfaction with New Zealand's science and technology reforms'. Specifically 70% of respondents in 1996 and 2000 disagreed with the statement: 'The management systems now in place are appropriate for the effective enhancement of research' and a similar proportion did not agree that, 'The changes in the organization of New Zealand science over the past four years have enhanced my situation/conditions for performing innovative research'. Perhaps this explains why 50% (in 1996) and 58% (in 2000) disagreed with the assertion, 'The way things are going with science and engineering careers in New Zealand today, I would recommend such careers to New Zealand youth'.

Thus, the success or otherwise of the CRIs at this most general level depends on the perspective. From the viewpoint of the politicians and bureaucrats, who are pleased that, 'CRIs have proved to be low-risk entities to the Crown's balance sheet', they are successful when measured as performance-based organisations. But for the scientists concerned with their working environment, the CRI commercial model is not successful.

At a more specific level, other conflicts are apparent. MoRST (2002) noted significant conflict between the public role of the CRIs and their commercial objectives. Externally, the CRIs are seen to be neglecting their public good role and internally the CRIs felt that a disproportionate emphasis is placed on their financial performance rather than their contribution to the national good. Not surprising it is reported that the CRIs want their owners, the Government, to make clear, '... the kind of business that they [the CRIs] are in'. This is a very surprising conclusion, given that it was believed that the application of market theory was to clarify the role and accountability of science.

Other analysts (Winsley 2003, Devine 2003) have also emphasised the conflict of purpose inherent within the CRIs. As stated by Devine, 'the current system forces the CRIs to put their own interests above that of the nation'. This duality of purpose also makes the accountability of CRIs difficult to define—are they accountable to the public for their public good or for their financial goals? These problems arise directly from the CRI Act.

This contradiction of purpose in the CRI Act also affects the potential for industry to become involved in CRI funding, one of the important goals of the reforms. At its worst, the desire to optimise profits makes the CRI competitors with the industries they were designed to work with. This is particularly noticeable in the biotechnology area, where the commercial stakes in terms of gene ownership are high. Devine (2003) emphasises this point, noting that the profit motive of the CRIs is a disincentive for them to create value in other industries. It is perhaps not surprising that New Zealand's largest industry, the dairy industry, has established its own research facilities independent of any CRIs, to conduct research on-farm, in processing, and in biotechnology. Indeed, it was recently announced that government scientists within the CRI AgResearch are competing directly with the dairy company Fonterra in respect to biotechnology relating to the dairy cow (RSNZ 2004).

More serious, in terms of the public perception of science, MoRST (2002) reported that the emphasis on financial performance, and with it, the requirement to optimise commercial revenues, was undermining the external perception of the independence, impartiality and objectivity of CRI scientists. The view was expressed that, 'They [CRIs] are seen as commercial companies and the scientists are thought to simply push the company line. This raises the issue of who can the public turn to for independent advice'. This issue was raised at the Royal Commission on Genetic Modification (2001) and could ultimately be fatal for New Zealand science: science, like the law, must be seen as independent of all considerations other than the pursuit of knowledge and understanding..

Another important purpose of the reforms was to better measure the performance of science in the belief that this would improve efficiency and productivity. The CRIs are required to report annually on their financial and non-financial performance. While there is no problem with the former, as noted earlier there are difficulties with measuring the non-financial performance of a science-based organisation. CCMAU (2002) noted that the CRIs are obliged to report on staff composition and science output, but have the discretion to choose their own measurements for non-financial performance. They reported that, 'Today, the non-financial performance indicators selected demonstrate considerable differences between individual CRIs and also highlight the fact that *performance in science and technology is inherently difficult to measure objectively*' [Authors' emphasis].

This problem is as old as science and is insoluble. Science simply cannot be measured in the same way as most commercial activities dealing in tangible goods (Ziman 1994, Easton 1997). This arises because the outcomes of scientific endeavour are not predictable or, as expressed by Einstein, 'if we knew what we were doing it would not be science'. Furthermore, even when discoveries are made, their value in financial terms cannot be assessed. It is only in hindsight that the economic benefits of science can be estimated. Devine (2003) cites the New Zealand discovery of lead–rubber technology as an example of this, but other more obvious and profound examples include the discovery of electricity and the relationship between energy and matter.

Contract theory requires that the inputs and outputs of any transaction can be defined and quantified (Boston et al. 1998), but since the output of science cannot be defined, its application to science is inappropriate. Despite this, contract theory has been universally applied in New Zealand to the management of science as part of the reforms. All science providers who are successful in receiving funds from FRST are required to sign a contract to deliver specified science outcomes. This is, as many scientists know, an exercise in futility; it is demeaning of science, wasteful of time, and simply adds transactional costs to the process of science funding.

So, too, is the application of the concept of contestability to science. Easton (1997) has argued that this notion of contestability is flawed when applied to science activity. As originally used in economic theory it refers to the market situation where competitors could freely move into and out of a market—in other words there are no barriers (tangible and intangible) to entering and exiting a particular market. As Easton noted, this principle cannot and does not apply to scientists and science groups. Science has become very specialised, and additionally, it takes many years, post-graduation, to develop the experience and 'track-record' in a particular discipline to be successful at attracting research funds. For this reason the notion that a scientist, or a group of scientists, can bid for funds in say soil science in one year and freshwater ecology or economics in another, is simply nonsensical.

But there is a further problem with the contestability argument. As noted earlier, it is a fundamental characteristic of science that it is a highly networked activity. Progress occurs over time because scientists publish, and hence share their findings. Competition among and between science groups is the antithesis of the spirit of science. It is ironic, therefore, that FRST, while officially retaining the principle of contestability, is now emphasising the importance of 'collaboration' between scientists, science groups, CRIs, and industry groups.

There is other evidence indicating that the application of contestability to science has destabilising effects on science and scientists. This concern is officially acknowledged. Both MoRST (2002) and CCMAU (2002) reported that the competitive nature of science funding is affecting the ability of CRIs to retain core competencies. Devine (2002) noted that, 'many [scientists] have a fear that they will be next to lose funding' and emphasised the need for more stability to maintain the pool of human capital—the most important resource—in science. These problems are a direct consequence of the inappropriate application of the principle of contestability.

It is suggested that the 'stunning level of dissatisfaction [among scientists] with New Zealand's science and technology reforms', as measured by Sommer & Sommer (1997) and Sommer (2002) is a result of the application of business theories developed for performance-based organisations, which are completely inappropriate from a normative organisation. As Zinman (1994) has pointed out, management tools and techniques 'can be very inhospitable to expertise, innovation, criticism, and creativity'. Overarching this is the contradictory nature of the CRI Act. This conclusion is consistent with the fact that similar 'market-led' reforms to the education and health sectors—other normative organisations—have also failed.

The contradictions and problems highlighted above would perhaps be of little consequence if indeed the reforms delivered their promise of greater efficiency and productivity.

One of the most rudimentary measures of science activity is the number of people involved. Bollard (1986) in his early review of government-funded science at the time of the introduction of user pays, recorded that there were 4923 people involved. As noted by CCMAU (2002), headcounts can inflate the actual science effort because of part-time staff and job-sharing and, consequently, they regard the use of full-time equivalents (FTE) as being more accurate. They reported that, in terms of researchers and research support staff, there were 3120 FTEs in 1999 and 3236 FTEs in 2001. [Unfortunately, the CRIs have not consistently reported their human resources on an FTE basis since their inception.] Nevertheless, it is difficult to believe that the discrepancy in these numbers is due solely to part-time workers and job-sharing.

Statistics New Zealand reviewed the R&D resources in 2003 and provided a time series in FTE employed by the CRIs from 1992 to 2002 (Table 4). These data suggest that there has been no real increase in the human capital employed in government-funded research, despite a 44% increase in gross revenue, as noted earlier.

Goldfinch (2001) compared the research performance of the CRIs relative to overseas institutions, based on their publication records over the period 1995 to 1999. He concluded that the most productive of the CRIs were as good as international standards. Jordan & Atkinson (2003) summarised the publication records of all CRIs over the period 1993 to 2002. They concluded that scientific output as measured by the number of scientific publications in international journals did not significantly increase despite significant increases in inflation-adjusted revenue.

A possible explanation for this is that, given their commercial imperatives, the CRIs have put more effort into gaining patents rather than publishing, noting that a patent cannot be granted if the research has been published. However, Goldfinch (2001) compared the rate of patenting in CRIs relative to the CSIRO (a public service model) and concluded that the CRIs 'do not seem to be hugely successful in obtaining patents'. This evidence suggests that the number of scientists and their scientific output has not increased despite large increases in revenue, which indicates a net decrease in productivity and efficiency.

The available evidence suggests that there are currently less scientists, including support staff, than in 1986, when user pays was first implemented, and that their numbers and productivity have not increased since the inception of the CRIs. Given that total CRI revenues have increased by 44%, this suggests that science efficiency has decreased as a result of the reforms. Hazeldene (1998) predicted this outcome from the application of market theory to normative organisations. In his words, such reforms simply increase the transaction costs of otherwise good services.

The empirical evidence accumulated over 10 years indicates that the commercial CRI model has not been successful in New Zealand. Major deep-seated philosophical and operational conflicts are emerging as a result of the ambiguity of the CRI Act and the application of management theories developed for performance-based organisation to normative organisations. These conflicts are predictable from management theory and possibly explain why most scientists are dispirited by their current environment.

A solution?

If the commercial model is not appropriate for a productive science organisation the question must be asked: Is there an optimal organisational model for science?

Devine (2003) and Winsley (2003), in their analyses, both suggested that the current policy/purchaser/provider split should be eliminated by amalgamating MoRST and FRST, and that the science providers be largely bulk-funded by industry sector, adding that there needed to be one body overseeing the whole process from policy, funding priorities and allocation, to research implementation and the sector involvement. They argued that these changes would improve efficiency by reducing layers of management, reduce transaction costs, and give clearer strategic focus to science management and activity. They also argued that CRIs should be redirected to undertake the research that the market cannot or does not want to do, emphasising the public good role of government-funded science. These changes alone will not overcome all the problems discussed earlier. To be effective, they should be coupled with the elimination of the principles of contestability and contract theory from science policy and management.

Similarly, it is imperative that the profit motive—the need for a return on investment in purely financial terms—should also be discarded, returning New Zealand science to a normative public-good role. This does not mean that science must become, as it was, the activity of a government department(s). The Not For Profit (NFP) organisational model (Hansmann 1980) not only allows expression of the normative science role but also allows flexibility. It is important to note that NFP does not mean that such organisations do not make profits. They can and they frequently do (Hansmann 1980). NFP means simply that the

Table 4: Human resources employed in R&D in New Zealand (Statistics NZ 2002).

	1991/92	1992/93	1993/94	1995/96	1997/98	1999/00
Researchers	1525	1556	1667	1498	1765	1631
Technicians	1503	1414	1476	1518	1211	1118
Support staff	839	781	834	968	840	696
Total	3868	3751	3977	3984	3816	3445

profits are non appropriable—they remain within the organisation (Hansmann 1980). In this sense they are still required to be efficient in their use of resources

If science is at a 'steady-state', with respect to government funding, as asserted by Ziman (1994) and experienced in New Zealand over the past decade, it can only expand if there is a growing financial input from the private sector. For this to occur there must be some motivating factor to encourage industry in this direction. Tax relief is an obvious mechanism. But involving industry in the new NFP organisations could have profound effects.

The current CRIs are already aligned to specific sectors (Goldfinch & Bellamy 2001) and it is reasonable to suggest that if they were converted to NFPs their ownership could be vested in both the Crown and industry. This could also include the involvement of industry in the policy and management of science. This would ensure commitment from the respective sector and would facilitate stronger, more cohesive links between science and industry. This need not compromise the core values and requirements of science. The deeds of trust of these proposed NFP organisations should be flexible to accommodate the requirements of their sector industry but should explicitly recognise and embrace the following principles and values:

1. Science and scientists must be free of all constraints that may compromise or undermine the independence, impartiality and objectivity of the science they undertake.
2. Science and scientists must be open to the process of peer review, and accordingly free debate and discussion is encouraged and the right to publish and criticise is protected.
3. Science outcomes cannot be specified and defined in financial and accounting terms and science is largely non-appropriable and to be undertaken for the public good.
4. Scientists and science organisations have a social responsibility, which includes the efficient use of resources, and consequently they must accept along with all sectors of society that their rights to resources are limited.
5. Science is predominantly a non-competitive activity, and scientific process and science quality are best enhanced by encouraging collaboration.
6. All citizens and customers have a right, without qualification, to information regarding the allocation and management of their funds.
7. Commercial involvement in developing science policy and objectives and in the management of science projects is accepted, but that the essential processes of science cannot and should not be controlled by commercial considerations.

These ideas are not radical or new. Indeed the *New Deal* (Arbuckle et al. 1988) suggested that the new science organisations could be either for profit or NFP. There are also good examples of the utility of the NFP model. The Cawthron Institute (established in 1920) and Dexcel (established 2002) are current examples of NFP trusts established to undertake science for a specific purpose. The former is privately owned while Fonterra owns Dexcel.

A final question remains: Who should manage these NFP organisations? Concurrent with the science reforms was the belief that management was a generic function and that a skilled, experienced manager could manage across the 4 × 5 organisational matrix. Operating a brickworks was deemed to require the same skill-set as operating a hospital. This could be so if the purpose and motivation of all organisations was the same. This is clearly not the case. Different organisational types require different types of management, based in the values and beliefs of the organisation. It follows that science should be managed by those who embrace the values and beliefs of science. This does not mean that only scientists should manage science, but it is likely that the pool of potential management skills will come from this background.

These changes, if adopted, would eliminate many of the current conflicts surrounding the purpose, accountability and measurement of the CRIs and their relationship with industry. More importantly, they would ensure that government-funded science is clearly for the public good and that science is seen and known to be objective, impartial and independent. Most importantly it would create a science environment that would be encourage and invigorate scientists to use their skills and knowledge to facilitate the transformation of New Zealand to a knowledge economy.

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