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article

The Cochrane Collaboration: institutional analysis of a knowledge commons

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Cochrane is an international network that produces and updates new knowledge through systematic reviews for the health sector. Knowledge is a shared resource, and can be viewed as a commons. As Cochrane has been in existence for 25 years, we used Elinor Ostrom's theory of the commons and Institutional Analysis and Development Framework to appraise the organisation. Our aim was to provide insight into one particular knowledge commons, and to reflect on how this analysis may help Cochrane and its funders improve their strategy and development. An assessment of Cochrane product showed extensive production of systematic reviews, although assuring consistent quality of these reviews is an enduring challenge; there is some restriction of access to the reviews, open access is not yet implemented; and, while permanence of the record is an emerging problem, it has not yet been widely discussed. The assessment of the process showed that the resource, community, and rules-in-use are complex, vary between different groups within Cochrane, and are not well understood. Many of the rules have been informal, and the underlying ethos of volunteerism where reviews get done are important features and constraints to the organisation. Like all collective efforts, Cochrane is subject to collective action problems, particularly free-riding and variable commitment, and the under-production of public goods and internal processes, such as surveillance of product quality and procedures for transparent resolution of conflicts.

key words Cochrane • knowledge commons • institutional analysis • Ostrom

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Background

This paper reports on an institutional assessment of Cochrane (formerly known as the Cochrane Collaboration), an organisation whose mission is the production of up-to-date systematic reviews of the effects of health interventions produced using standard procedures. It is unusual as an organisation as it was built from the bottom up: at its launch in 1993 it was entirely volunteers who were committed to producing the systematic reviews (Box 1). With over 7000 reviews published by 2017, Cochrane is an important producer of knowledge in health.

The characteristic of knowledge as a shared resource has drawn scholars, the most notable of whom is Elinor Ostrom, to see it as a commons, the knowledge commons – a shared resource. With Cochrane now in existence for almost 25 years, we sought to examine how Ostrom's conceptual approach and methods of analysis could apply to Cochrane. The objective of the work reported here was to explore whether this analysis provides insight: first, as an example of applying the knowledge commons to medical and public health knowledge; and second, in how Cochrane operates, to help the organisation and its funders reflect on this complex organisation to improve strategy and development over the next decade.

Ostrom built on her extensive work analysing the natural commons (Ostrom, 1990) such as community-managed forests and irrigation systems, to propose a similar approach for analysis of the knowledge commons (Hess and Ostrom, 2011). Others, most notably Frischmann and colleagues, have modified and added to (Strandburg et al, 2014) the approach of Ostrom and Hess, arguing that the analogue to a natural commons is a culturally constructed commons,

... environments for developing and distributing cultural and scientific knowledge through institutions that support pooling and sharing of knowledge in a managed way, much as a natural resource commons refers to the type of managed sharing environment for natural resources.... (Frischmann et al, 2014)

To carry out an assessment of Cochrane with this lens we used a framework that encompasses both the product (the systematic reviews) and the process (the workings of Cochrane). We use the Institutional Analysis and Development (IAD) framework proposed by Ostrom and her colleagues (Hess and Ostrom, 2011) and modified by Strandburg et al (2014) in their analysis of the Rare Diseases Clinical Network as a knowledge commons.

In the first phase of our work, we considered Cochrane in relation to the knowledge commons' literature and how the organisation maps on to theory. With this frame, we could then identify what was important to consider in a rapid evaluation of the knowledge produced; the institutional analysis surrounding its production; and the collective action problems that are recognised within knowledge commons.

What is Cochrane?

Launched in 1993, Cochrane has as its primary objective the production of up-to-date, reliable systematic reviews about the effects of healthcare to inform healthcare decisions

and research priorities. Systematic reviews are now regarded as primary research: the critical appraisal identifies weaknesses and strengths in the original data not identified by referees and often only apparent when taken in the context of structured, systematic appraisal of other research asking a similar question; and the bringing together of different studies asking a similar question can generate new knowledge.

The Cochrane Collaboration, formally launched in 1993 at the 1st Cochrane Colloquium in Oxford, was a response to a challenge to the medical profession 20 years earlier from Archie Cochrane (Cochrane, 1972) to provide better evidence for healthcare interventions. In 1995 Cochrane was registered as a Company and a Charity under English law and the Executive Office established.

Cochrane's 'Strategy to 2020' (Cochrane Collaboration, 2014) sets four goals and associates targets with each. The goals are to:

- 1 Produce evidence, principally through high-quality systematic reviews
- 2 Make evidence accessible and useful around the world
- 3 Advocate for evidence as the leading advocate for evidence-informed healthcare
- 4 Build an efficient and sustainable organisation

At the centre of Cochrane are Cochrane Review Groups (CRGs) whose members prepare, maintain and update systematic reviews known as Cochrane Reviews (CR). Each group has an editorial base where a small team, led by a Coordinating Editor (CE), who has final sign-off authority for the product of the group, together with the Managing Editor (ME) and a Trials Search Coordinator (TSC), support the production of CRs. Authors propose topics for review, the protocol for which must be approved by the CE in dialogue with CRG Editors. This process takes into account reviews in other CRGs. In addition to CRGs, Cochrane also has Methods groups and Cochrane Centres that support authors and CRGs in geographic and linguistic areas. As of March 2017, there were 52 CRGs and representatives in 43 countries.

Cochrane developed rapidly during its first decade when its procedures and methods were developed. At this time, the approach of the central executive was hands-off, and allowed considerable variation between CRGs and the way they approached their task. The Executive Office was small (a total of five FTEs in 2002) with limited involvement in details of work programmes of individual CRGs. Concern about the quality of CRs has been a recurrent theme for Cochrane almost from the beginning. It continues today and is at the centre of current discussions.

The first full-time Chief Executive Officer (CEO) was appointed in 2003 and a publishing agreement with Wiley-Blackwell was put in place; a new agreement was signed in 2013. National governments purchase licences that provide free access at the point of use in Ireland, Australia, Finland, Norway and the United Kingdom, and in India. Free one-click access is available to all people living in low income countries (HINARI bands A and B).

In 2014, a new CEO developed a strategic plan with the organisation, commenced a review of governance, and rebranded the Collaboration 'Cochrane', dropping the word Collaboration. By 2015 the Cochrane Central Executive had more than 50 full-time staff.

Methods

The approach

Hess and Ostrom (2011) see knowledge as ‘all tangible ideas, information, and data in whatever form’. They also follow the division of knowledge into data-information-knowledge. Data is ‘raw bits of information, information being organised data in context, and knowledge being the assimilation of information and understanding how to use it’. (2011, 8). Knowledge can be gained through experience or study, is cumulative (2011, 9), and must be passed from one individual to another to have public value (2011, 53). The cumulative and aggregative nature of knowledge means that storage of past knowledge, and access to the store, is critical. Following this approach, by producing systematic reviews Cochrane is engaged in the production of knowledge. Cochrane, a complex organisation that utilises resources held in common (common property resources), facilitates and promotes the production of knowledge.

Analysis of outputs

Assessment of the output (systematic reviews) was made against the attributes set by Cochrane itself in its first strategic plan 2020 (Cochrane, 2009). We examined these in relation to four main parameters, three of which are from the strategic plan: the *quantity* produced; the *quality*, in terms of international expectations; and the *access* to the product, or if it is restricted in some way. The fourth, and final, aspect we examined was the *permanence of the record* – that is, that the product is permanently accessible, with little risk of it being destroyed or unavailable later. Although this is not in Cochrane’s strategy, it is critical to the long-term effectiveness of Cochrane (Waters, 2011).

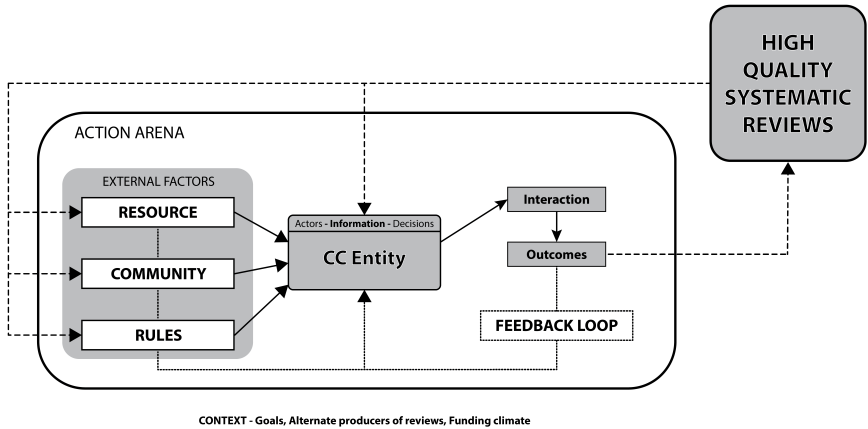
Institutional analysis

The Institutional Analysis and Development (IAD) framework was developed by Ostrom and colleagues as a diagnostic tool and as the basis for comparative institutional analysis of shared resources such as the Cochrane. Using the approach of Ostrom (2011), Cochrane can be seen as a common pool resource providing a flow of resource units derived from social and human capital and funds over time. Multiple individuals can use this resource, which renders it liable to exhaustion and degradation. To prevent exhaustion and depletion of the resource, access rights are held in trust by Cochrane, which assigns or appoints individuals to roles related to the organisation’s goals. The rules governing access and other activities convert the common pool resource to a common property resource owned by Cochrane, the primary product of which, systematic reviews, is, potentially, a public good.

The IAD framework, as applied to Cochrane, is shown in Figure 1 – it consists of three main parts. First, the three vertically-aligned boxes on the left-hand side of the diagram draw attention to the role of three components:

- *The resource* – comprising the social capital, the human capital, the infrastructure and the funds
- *The community* – comprising those who produce the reviews and infrastructure (methods and procedures used by Cochrane) as well as those who provide policy and utilize the final product
- *The governance and the rules-in-use* (those rules generally known and enforced), both formal and informal, which provide the basis for governance of the organisation.

Figure 1: Action situation for Cochrane



Source: Adapted from Ostrom and Hess [22]

The process plays out in the *action situation* – the middle portion of the diagram is the general representation of an interaction between at least two individuals who meet to achieve a certain outcome. The decisions made depend on the information and knowledge available to the individuals, the control each has over their own decisions, and the net costs and benefits thought to be associated with the decision. Examples of action situations range from formal meetings of Cochrane, to meetings of authors working on systematic reviews. The action arena works in a context, which includes goals of the organisation, the funding climate, and alternative producers of systematic reviews.

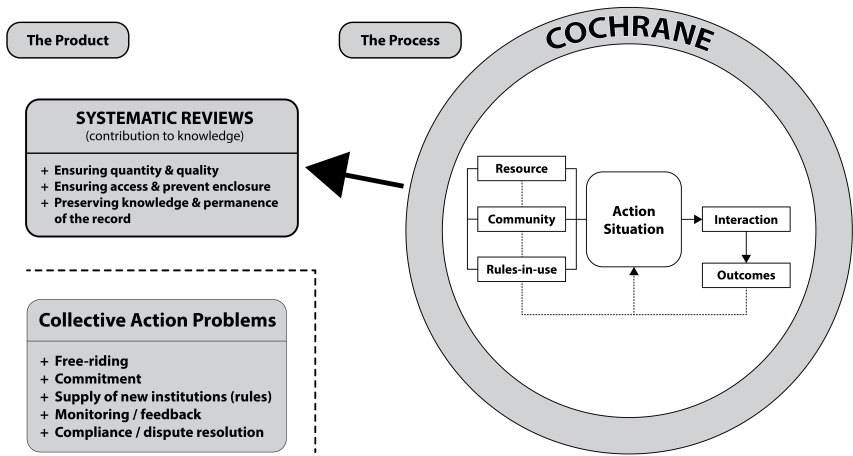
Cochrane is multi-level. The operational level is where reviews are prepared by authors; at the CRG level (referred to in institutional analysis as the collective-choice level) decisions that affect the operational level are made; and at the central level (referred to in institutional analysis as the constitutional level) decisions that affect the collective-choice level are made. The relationship between these levels means that Cochrane is also hierarchical – decisions at one level constrain actions that can be taken at the level below.

The manner of interaction between the various individuals at each level affects whether the group will be successful in producing quality reviews and, when aggregated, the overall success or failure of Cochrane in producing systematic reviews, as well as in generation and utilisation of resources. The provision of information about these two forms of product requires *feedback mechanisms*, one which provides information about the quantity and quality of systematic reviews, and one about resources.

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Cochrane is an example of an entity whose infrastructure, resources, and rules facilitate and promote the production of knowledge, in this case systematic reviews which, provided they are widely accessible, have many of the characteristics of a public good. In other words, once they have been produced and released, use by one person does not prevent another person from using the review, and once the review is available to one person it is available to most. The ultimate contribution to knowledge by the systematic reviews also depends on their permanence and quality. This relationship between Cochrane, collective action, and knowledge – the knowledge commons – is shown in Figure 2.

Figure 2: The Cochrane Collaboration as a knowledge commons



Voluntary groups working together require collective action, but this has its problems (Figure 2). Individuals participating in these groups experience both incentives and disincentives to act. Depending on their relative influence, the balance of incentives may lead some people to conclude that they can *free-ride*, obtain the benefits of the group without paying the costs of making a significant contribution.

Thus, our evaluation is framed from Ostrom's theory and the knowledge commons literature. We identified three main areas for our appraisal:

1. The knowledge produced, in relation to quantity, quality, access and permanence
2. The institution, in relation to the product, in relation to resources used, community, governance / rules in use, the setting and mode of interaction between participants, and feedback (Figure 1)
3. Collective action problems found with 'commons', including free-riding, commitment, supply of new institutions (rules and procedures), monitoring and feedback, and compliance and dispute resolution (Figure 2).

Data collection

Our sources of data were existing publicly available documentation and interviews with key informants. Sources of information used for each framework element are shown in Table 1. Documentary sources included published literature, online sources, review of the Cochrane Database of Systematic Reviews, the Cochrane Collaboration Strategic Review, and minutes of CCSG (Cochrane Collaboration Steering Group). Data were collected and discussed by the review team daily, and interviews done with at least two members of the team participating.

We interviewed 15 key informants drawn from a range of roles in Cochrane. These included those involved in the initiation of the collaboration, the current director of the UK Cochrane Centre, the current CEO and Coordinating Editors, CEU staff, a Managing Editor, the senior executive of the National Institute of Health Research (NIHR) with responsibility for the NHS funding of Cochrane, and authors attending a Cochrane meeting in Manchester. We also had correspondence with a member of the publisher's staff about the number of reviews produced and the extent to which access to the reviews was open (see Table 1). All interviewees were employees of Cochrane or senior administrators, who we judged were not vulnerable and thus requiring ethical committee approval. Interviewees were briefed on the aims of the study and the purposes of the interviews were fully explained to each participant. We outlined that the work was research aiming to apply Ostrom's IAD framework to an example of a knowledge commons, and that this would be submitted for publication; and we also intended to identify useful insights that might help Cochrane in developing its long-term strategy, to be communicated to Cochrane and the participants at presentations at Cochrane meetings and through publication. We also assured participants that the results would be presented in a way that would preclude their identification. Having explained these, we then sought and obtained verbal consent. The content of these discussions was initially guided by topic guides based on the framework, preliminary reading and discussion, and our own experience. Interviewees were encouraged to raise items beyond these guides if they wished, and most did so. We had multiple meetings with some interviewees, with the express purpose of clarifying information presented earlier and to discuss points emerging from our analysis. Sometimes these exchanges were continued by phone and email.

Review of interview notes and discussion after each interview meant that analysis was ongoing with constant analysis between interviews. Concurrently, we reviewed documents on various aspects of Cochrane. Thus, information from interviewees, currently in a range of roles as well as those whose roles had changed over time, together with information and analysis based on documents from a range of sources, allowed us to check information, fill gaps, elaborate on emerging themes, and triangulate against phenomena and issues from several perspectives. The authors discussed the analysis and interpretation iteratively and reached consensus about judgements within the framework derived for the analysis.

Within each component and area of the framework, analysis was continuous and inductive. As findings were placed in the framework, where indicated we followed up with further document analysis and, where possible, interviews and emails.

The research was carried out between March and June 2015, and updated in April 2017.

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Table 1: Sources of information

IAD category	Aspects assessed	Source of information
Product	Quantity, quality, access, permanence	Cochrane records, NHS, minutes of meetings, published papers and reports, discussions with NHS, Cochrane documents, discussions with Wiley, published literature
Process	Resource, community, rules-in-use	CRGs, authors, managing editors, and other key informants
Collective Action problems	Free-riding, monitoring, dispute resolution	Editors, authors, newsletters, articles in journals, blogs, key informants

Some of the strengths of the analysis were being able to draw on sources across the organisation for all elements of the framework, and from individuals with a long institutional memory at a senior level. Some of the limitations were that the number of people interviewed was limited, and we depended extensively on publicly available documents.

Reflexivity

We were aware that engagement of two of the team in Cochrane was a strength, but needed careful reflection and attention as to how we collected, analysed and interpreted data. We discussed this as a team as we developed our methods.

One of us (PH) had limited previous Cochrane involvement, was the team leader, and specialist on institutional analysis (IA) and the knowledge commons. PH was a team member, along with PG, for one systematic review which used Cochrane-like methods but was published outside the Cochrane system. He had no other involvement with Cochrane until this study, but was recently involved in an institutional analysis of the HIV/AIDS control programme in Indonesia. Building on this earlier work he initiated this study of Cochrane as an example of a successful organisation built from the bottom up with a strong participatory approach. The effect of his limited previous Cochrane experience meant that, in contrast to PG, he brought to the analysis a different and non-Cochrane perspective.

Interviews were led by PH in partnership with PG, who has been involved in Cochrane since its inception as an author, and as a CE for systematic reviews covering a wide range of topics; he had also been a member of the Cochrane Co-ordinating Editors Executive. Whilst his familiarity with Cochrane facilitated appointments, it was important to minimise the extent to which this involvement adversely influenced judgments about the analysis. Discussions after each interview explicitly addressed this issue. The third author, AMS, is currently working as part of Cochrane, and thus has detailed knowledge of current processes, procedures and debates; she helped source materials, analysed data and participated in the discussions and analysis.

At the outset of the review all three authors believed that evidence synthesis is a useful and important scientific endeavour.

Results

The product

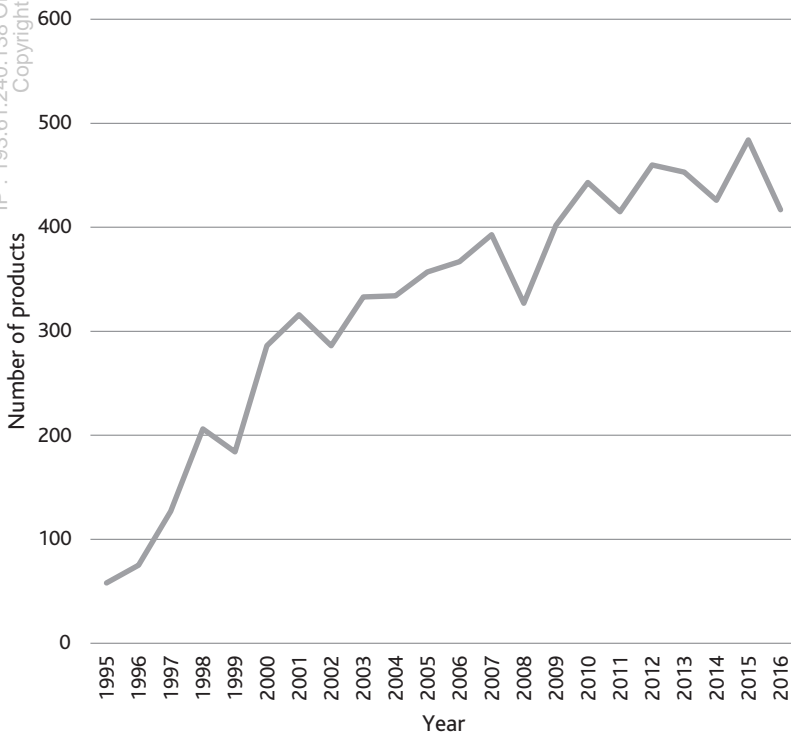
In presenting the findings we focus on the main Cochrane products: new reviews and updates of previous reviews. We concentrate on the four critical aspects of Cochrane addressed in the first section – quantity, quality, access, and permanence (Figure 2 and Annex 1).

Quantity

The quantity of new reviews has been carefully monitored since 1995 through custom software. Interrogation of this custom software (*Archie*) in December 2016 shows that over 7000 reviews have been published since this monitoring began. The number of new reviews published each year increased rapidly in the early years and is now consistently over 400 (Figure 3). In the last 15 years, approximately two-thirds of these new reviews have been produced through CRGs under subsidy from the NIHR (authors' analysis of information supplied by NIHR).

There is considerable variation between the 52 CRGs in the number of reviews produced since Cochrane commenced. The top 15 CRGs (by total number of reviews since 1993) have produced half of all new reviews. Two CRGs, those for pregnancy and childbirth, and neonates, have produced one-tenth of all reviews.

Figure 3 Cochrane Library, number of reviews, all groups, 1995–2016



Source: Authors' calculations using data derived from Archie, (accessed 13/05/2015).

Quality

Variation in quality of reviews, and what to do about it, has been a topic of discussion within Cochrane almost since the first review was produced: for example, the topic was discussed at the 1996 CCSG meeting in Adelaide and a paper to address the issue commissioned. By the year 2000 one of the advisory groups reporting to the CCSG was a Quality Advisory Group. Discussion of quality continued at subsequent CCSG meetings and in 2008, under continuing pressure from Co-ordinating Editors, a proposal to appoint an Editor in Chief (EIC), with a primary aim of improving quality, was accepted along with a proposal for development of explicit training activities to support authors. An Editor in Chief (EC) was appointed in 2009, and a Board of Co-ordinating Editors to work with the holder of this new position was created at the same time.

Amongst the early attempts to assess the quality of Cochrane reviews was the work of Olsen et al (2001), who assessed the quality of a sample of 53 Cochrane reviews published in 1998. Almost one-third of reviews had major problems which included biased conclusions and problems with methods. Smith et al (2015) examined 788 reviews published in 2007 and 2011 – 37% of pre-specified outcomes were not reported. In the light of the enduring quality discussions, the EIC worked with Co-ordinating Editors to establish the ‘methodological expectations of Cochrane intervention reviews (MECIR)’, a collection of recommendations and mandatory elements for the conduct and reporting of new Cochrane reviews. In 2013, the Central Editorial Unit (CEU) (2015) started screening all new and updated reviews submitted for publication. They screened a total of 56 reviews published in August 2013 and August 2014 – the proportion of reviews judged to be fully or partially compliant with all quality items was 18% in 2013 and 64% in 2014. The Central Editorial Unit continues to screen projects to assess quality, and this is now seen as the first stage of developing a more systematic approach to quality assurance (Central Editorial Unit, 2015). Debates continue as to whether this is improving quality overall, or simply catching reviews that are sub-standard. However, the results are apparently not made public, and how the analysis by CRG is shared with the CCSG (now the Governing Board), and what decisions arise from any discussions at this level, is not clear. In the meantime, anecdotal evidence indicates that the variation in quality persists and that there is considerable difference in quality between CRGs (Misso et al, 2017).

Access

In both the first and second Strategic Plans of Cochrane the second goal was to promote access to the reviews. This goal is at variance with what happens in practice: under commercial publishing, access has generally always been restricted to those individuals, organisations or countries that paid an annual licence, up to 2013.

More open access (OA) only became possible in 2013. The current agreement with Wiley allows for either Green OA (12 months after publication) or Gold OA (immediately on publication after payment of an article processing charge (APC) by the authors of US \$5,000 for the initial publication and a slightly reduced fee each time the review is updated). Important points of the agreement are as follows:

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- All reviews and updates published before February 2013 are behind a paywall, or are limited to users with access to a country or institutional licence
- Reviews and updates published after 1 February 2013 are available immediately if Gold OA and after 12 months if Green OA
- Earlier versions of reviews are not available under OA even when an update is available via Gold OA
- In countries with annual licences (UK, Australia, Canada, NZ, India) access is free at source
- In low- and middle-income HINARI A and HINARI B countries, and those in the Caribbean and Latin America region covered by BIREME agreements, access was free to anyone with an IP address from that country up to January 2016. This free access can be reviewed by the publisher, and therefore potentially removed, at any time
- For Gold OA, authors sign a licence for publication form which allows for immediate unrestricted access and non-commercial reuse provided the original article is cited (CC-BY-NC or CC-BY-NC-ND licence), details of which are shown in Creative Commons (2015)

This new agreement took effect in February 2013. In the year 2013–2014, four Gold OA reviews were published. The Green OA started in February 2013 with a 12-month embargo on OA access. Therefore, there were no Green OA reviews available for free until February 2014. In the year 2014–2015, a total of 421 new reviews were published, with 411 of these using the Green OA method, and only 10 using Gold OA. Similarly, of 498 review updates over that time, 492 were Green OA, and only 6 were Gold OA. For the period 2015–2016, 426 out of 439 new reviews and 459 out of 470 review updates were Green OA (13 new reviews and 11 review updates as Gold OA).

Thus, access is limited in three ways. First, those in countries without an annual agreement – most of the world – either have no access, access to only a limited subset of reviews, or access is only possible through non-profit organisations such as universities and hospitals, in effect limiting access to individuals employed by or associated with those organisations. Second, access to all earlier versions of reviews is behind a paywall, effectively limiting access to the previous record. Third, future use of the content of reviews is limited – while Green OA reviews can be deposited on personal or institutional repositories after the embargo period, the licence does not allow for further distribution or reuse of the data by others. Gold OA does make use of a Creative Commons Licence agreement after payment of an APC, although this is restricted to the NC and NC-ND versions of CC-BY agreements. The overall effect of these restrictions is that what was a public good has now been partly enclosed, limiting its free availability (see Chan and Costa, 2005), the overall result of these restrictions is that what was a public good has now been partly enclosed, limiting its free availability to many and turning the reviews into a commodity available to those in high-income countries and, should they wish, to high-income groups in low-income countries; and limiting further commercial use for translation and technologies such as data mining and semantic tagging.

While the APC required by Wiley is in line with other large hybrid OA journals such as *The Lancet* or *BMJ*, this fee is considerably more expensive than the APC required by exclusively OA publishers (for example, Public Library of Science). Although there is

a waiver system in place when the first author is from an HINARI-A or HINARI-B country, this again limits the use of the Gold OA option to those in high-income countries, and within high-income countries, limits use to those authors or CRGs who have access to funds set aside for such dissemination strategies.

Permanence

There are three main aspects to permanence. The first relates to the control over review content which rests with the CRGs who can alter reviews. Whilst major changes should result in the review having a new edition version, a new date and a new citation on MEDLINE, smaller corrections can be made at the discretion of the CRG and not recorded anywhere. However, there are examples of quite large changes to findings being made, and the CRG simply overwriting the previous published version – thus destroying public access to the earlier version. In addition, review groups currently have the discretion to withdraw reviews, for reasons set out in the Cochrane Editorial and Publishing Policy Resource, including where the review is substantially out of date, or where there has been a breach of the commercial sponsorship policy.¹ When a review is withdrawn, it is flagged as such on the Cochrane Library and only the title, coversheet, and reason for withdrawal will be published; the MEDLINE abstract remains, but with the prefix of ‘withdrawn’. Where there are serious errors in a review, a separate policy for withdrawing the review in consultation with the EIC is now in place.²

The second aspect relates to publication. In the period 1994–1998, when new editions of reviews were produced they replaced the older versions and the previous record was lost from the published product, although archives of the CDs published quarterly are held at the UK Cochrane Centre. Now the Cochrane Library archives old editions and they are available online, but behind a paywall. Whilst this has assisted with overcoming the almost automatic impermanence of the previous system, access to the permanent record is now limited.

The third aspect relates to the publishing contract with Wiley. Whilst a print journal can remain as a permanent record once printed on paper, continued access to the Cochrane Library is dependent on the contractual commitment by the publisher, and assumes the publisher remains in business. Grey areas include the commitment to providing access should the publisher change hands. There is currently no agreement with a third party regarding permanence of the Cochrane Library should the publisher fail.

As the Green OA model gains traction, and more reviews in the Cochrane Library fall within this grouping, authors will retain the right to deposit their reviews in institutional or other repositories after the embargo period. Cochrane reviews published before February 2013 cannot be deposited in this manner; those published between February 2013 and September 2016 can be deposited by the lead author; and those published after 21 September 2016 will automatically be deposited in PubMed Central (PMC) 12 months after publication, although it remains the author’s responsibility to authorise this. When Gold OA reviews are updated, failure to continue with the Gold OA publishing model (that is, to not pay the APC and to have the review embargoed for 12 months before depositing in PMC), results in the risk that more people will have access to the ‘old’, OA version of the review than to the up to date review. These rapidly changing developments raise new complexities with version control and permanence with reviews that are updated, and the implications

of this have not been fully thought through. Overall, the permanence of the record is a key consideration in terms of the knowledge commons, but much more thought is required to cover the myriad of bases to help assure this within Cochrane.

The process

The general mode of operation in producing reviews has been to place responsibility for implementing editorial policies contained in the Cochrane Handbook (and more recently within MECIR standards) with the CRGs and, therefore, with the Co-ordinating Editors and Managing Editors. This devolution meant that each CRG developed its own approach within a broad, overall understanding of Cochrane's mission, objectives and processes. The result was considerable, largely undocumented, variation between the CRGs in processes and quality of output.

Within the CRGs, and given the role played by the Co-ordinating Editors, decisions on contentious issues are likely to be made by the leadership. At the same time, daily operational decisions are usually made by the Managing Editor, Editors and the authors. The distributed nature of Cochrane means that there is little incentive for CRGs to work together.

What was essentially an internal Strategic Review of Cochrane, published in 2009 (Cochrane, 2009), begins by recognising that most of the contributors are not employed by Cochrane – these are the often mentioned ‘volunteers’ of the Collaboration; and that the structure of the collaboration is highly decentralised with a high degree of autonomy for each group. Because of this, and the variety of settings in which Cochrane groups fund and organise themselves, there is necessarily a need for flexibility in the way the various groups operate. The review recognised that the environment in which Cochrane operated was changing, the most important factors of which were:

- Dramatic increase in number of producers of non-Cochrane systematic reviews
- OA publishing model
- Increased workload with success of Cochrane
- Increased complexity of problems under review and the methods being used

Assessment against IAD framework

We examined the current function of the common property resource (CPR) by the types of information identified from use of the IAD framework. Details of these results are shown in Annex 1, which also shows a brief description of each variable. Where there have been changes in the 20 years of Cochrane we show these for the first and second decade separately. Overall, these results show that:

- Resources are a complex mix of social capital, human capital and funds – their relative importance is not well understood and may vary between groups
- Of the three community groups, the most critical for assuring outputs and least understood are the various 52 collaborative review groups. Little is in the public domain as to what is the same about them, what is different on comparative quality, variation in resources, or measures of their efficiency

- Rules / governance – the formal and informal rules reflect the distributed nature of Cochrane and allow considerable variation between groups in the way they operate; this variation is likely to be a source of both strength and weakness but neither is well understood. Some are informal, such as not rejecting any review, despite how poor the quality; others are more formal, such as how recent a search should have been carried out on a new review
- Action situation – whilst the underlying ethos is volunteerism the motivation of individuals varies from altruistic to selfish; the factors which affect motivation are not well understood, and increasingly grant funding and salaries are attached to review production
- Feedback – there is no attempt to monitor quality on an ongoing and detailed basis. There is little feedback to groups on the quality of their work and almost none of this feedback is public

Assessment of collective action problems

This is the rectangle at the base of Figure 2. The CRGS produce the systematic reviews which are the acknowledged output for which Cochrane is well known. The initial members of Cochrane formed the CRGs, agreed on basic common procedures, and produced the reviews. Many were highly skilled in their individual fields and committed to rising to the challenge set by Archie Cochrane. In carrying out this work members received personal gratification as well as professional acknowledgement from their peers. Given that most members were in academia or closely allied pursuits, such as the civil service, there was an ongoing negotiation between members and editors as to the input required and the way in which that input would be acknowledged, especially authorship of reviews which is seen in academia as research output.

The distributed nature of Cochrane initially meant that there was a small central unit, whose task was limited and essentially administrative, and that the CRGs were relatively autonomous; they were, however, expected to prepare reviews using the agreed overall set of procedures, and to present their product in a uniform framework. Within this framework, CRGs operate quite independently of one another and of the central executive. Consequently, there is variation in the output of the groups, both in quantity and quality. Although there has always been much discussion of quality, systematic monitoring of it has only recently been put in place. At the same time, other groups produced new procedures, work that was particularly intense in the first years of Cochrane.

Commitment of members to the cause varies, as does their motivation. Some continue to be driven by the challenge from Archie Cochrane, others are driven by the knowledge that joint authorship on another Cochrane review will bolster their publication list, with all the possible combinations in between. Some, rising to the challenge from Cochrane, are not concerned with recognition, others see opportunities for recognition that requires little input.

As these variations play out it is assumed that individuals are driven by professional standards and that, whilst quality may vary, overall it would be at a high level. Thus, little attention was given to monitoring quality, even though it was a persistent topic of discussion within Cochrane. There has been only limited discussion of the need for new rules, procedures and methods as the context within which Cochrane operates changed.

This decentralised structure and minimal supervision meant that differences between CRGs and with the Central Executive were often avoided, sometimes ignored, and on the limited occasions on which they were addressed, dealt with in non-transparent ways. This situation persists today. There is no accepted public mechanism for articulating disputes and searching for their resolution.

More recently the role of the CEU has changed, moving from a staff of five in 2002 to over 50 now, a ten-fold increase in staff numbers. There has been little explicit discussion of the implications of this increase in central resources for the relative roles of the CEU versus the CRGs and other groups, essentially a discussion between the central salaried staff of Cochrane and the volunteers, those responsible for the reviews on which the organisation's reputation is based.

Because Cochrane is voluntary, self-organised and produces public goods (in other words, it is difficult to exclude people from obtaining access to the good) there are considerable opportunities for free-riding. Free-riding within the groups (for example, in CRGs) occurs when an individual obtains the benefit of joint authorship of a review without making a commensurate level of input. Other aspects of free-riding are people using the Cochrane badge to obtain funds or credibility for other purposes; and others to be peripherally involved in the work but still gain salaries or travel funds for ostensibly contributing to the product. The way in which these problems are managed depends on the CRG and may vary between them depending on their size, and characteristics such as the levels of social and human capital, ability to monitor individual input, conflict resolution mechanisms, and ability to impose sanctions.

Discussion

We discuss the IAD analysis in four parts. In the first, we discuss the knowledge produced by Cochrane; in the second, we discuss Cochrane itself and the way in which the resource is managed; in the third, we discuss collective action problems of Cochrane; and in the last part we discuss some ways of strengthening Cochrane's performance and sustainability. We conclude that Cochrane can profitably be viewed as a knowledge commons whose primary purpose is to produce and share knowledge through systematic reviews of health interventions. Cochrane produces this knowledge by group management of a complex mix of resources – social, human and financial – as common property. Because the resources are finite, rules, both formal and informal, govern access to the resource and the ways in which it is used, and influence the success and sustainability of the group effort. As a voluntary collective effort, Cochrane is subject to collective action problems that also influence its output and sustainability.

Cochrane, now into its third decade, has made an important contribution to efforts to respond to the challenge set by Archie Cochrane. The organisation has grown from the bottom up, even if with a considerable public subsidy, and has now produced more than 7000 reviews, with a current production rate between 400 and 500 systematic reviews per year.

The actual reviews, widely seen as definitive summaries of what is best practice based on knowledge to date, influence clinical and public health practice in many settings. Further, the methods and approaches developed by Cochrane since its inception are now widely used by individuals and groups in the development of policy and guidelines in both national and international organisations. Nevertheless,

the assessment indicates problems and issues and, in summary, we conclude that the continued success and sustainability of the Collaboration depends on addressing:

- Enduring problems with the knowledge output of Cochrane
- Management of the complex resource base
- Collective action problems

The knowledge produced

The utility of the knowledge produced depends on the quality of the reviews, the extent to which they are widely accessible, and the permanence of the record.

Quantity and quality

Cochrane led the way in systematic reviews of the effects of health interventions. The view from within and without Cochrane was that they had set new standards for the preparation of systematic reviews through provision of strict guidelines, and thus their work was less prone to bias. More than 20 years later there are many other sources of systematic reviews, although no other sources commit to updating. Some commentators and authors openly challenge Cochrane because of the variable quality of its reviews. At the same time, within the organisation there is ongoing dissatisfaction, from a range of sources, with the editorial process which is described as long and cumbersome.

A search for reasons for the quality problems uncovers abundant anecdotal evidence that the workload of Co-ordinating Editors is heavy, with the result that protocols and draft reviews may sit for long periods at editorial base waiting for review and, hopefully, approval. Data from the CEU indicate that the median time at editorial base for protocol development is approximately nine months and for reviews is one year. These long waits result in long periods of time from initiation to publication – the median time is almost two years – with little indication that it is decreasing. Authors consistently rate delays at editorial base amongst their main complaints with the Cochrane system (Misso et al, 2017).

Thus, the factors contributing to the variable and persisting quality concerns are various, and many of them are structural rather than the result of the inadequate skills of authors. The dilemma for Cochrane is that its reputation is dependent on continuing to produce systematic reviews of high quality, even as quality is seen by many as the most important problem for Cochrane (Misso et al, 2017).

In response, in 2008 Cochrane appointed an EIC and, in 2012, a new CEO. Cochrane now has a central staff of approximately 50, ten times the number at the turn of the century. Nevertheless, an EIC, a CEO, and more than 40 new staff later, the quality problem continues.

There is an apparent reluctance on the part of the Central Executive and, perhaps, the CCSG to make the results of quality assessments public. There is a similar reluctance to make performance assessments of CRGs public and to withdraw the privileges of those who are not producing at an adequate standard. There is no ongoing systematic attempt to routinely survey quality or to understand what the problems are. Whilst there is a list of centrally sponsored activities aimed at improving quality they do not

appear to arise from a rigorous assessment of the problem or a coherent strategy for improvement.

Moves to more systematic surveillance of quality should go beyond reliance on journal impact factors to use of the more comprehensive approach to metrics discussed in the recent report by Wilsdon et al (2015).

Access

The high ambition of universal OA to Cochrane reviews features in both the first and second strategy documents and in the Policy Manual (Cochrane Collaboration, 2014): ‘We will achieve universal open access to Cochrane Systematic Reviews immediately upon publication for both new and updated reviews, and the archive of existing published reviews’ (2014, 112). However, the reality is quite different for potential users in many countries. Experience so far indicates that the predominant mode of publishing under the new model will be Green OA, with the result that many will not have access to new reviews for 12 months after publication, earlier versions of reviews will not be available at all, and ‘use’ is restricted because availability of the CC-BY licence itself is limited by the publishing agreement. Thus, expanding access and availability for other uses remains a crucial challenge for Cochrane.

Permanence

As in all scholarly publications, the system of references in a Cochrane Review links the current work to that which has gone before, the actual studies that form the input for a systematic review. The linked works represent the common pool of knowledge – the knowledge commons (Waters, 2011, 146) – for that particular topic. It is vital that a reader can check the references if she wishes. Her ability to check the references depends on a ‘reliable, ongoing system for preserving the knowledge commons’. The Cochrane Library was digitised from its inception in 1993, when it was distributed on floppy disks, and subsequently online. As such it is subject to the issues of preservation that now confront all scholarly journals distributed online – as Waters (2011) writes: ‘This is the process of ensuring that the knowledge commons endures (Suber, 2011) – that scholarly materials are available for citation and, if cited, are available for consultation and further study’. The first issue is that digital materials are often less permanent than we assume. Thus, Klein et al (2014) assessed issues related to reference rot for more than one million citations in science, technology and medicine journals published between 1997 and 2012. They view reference rot as due to both link rot (the resource referenced no longer exists) and content rot (the content of the resource identified has changed over time). Twenty percent of articles suffered from some form of reference rot. Although there have been no similar assessments made for the Cochrane Library, the situation is likely to be similar.

A long-term problem relates to the potential disappearance from the web of portals hosting journals from sale or failure of the journal. Some technical solutions to long-term digital archiving are in development – these include tracking where digital journals are archived, and specialist sites to ensure that journal articles can be accessed even if the portals that host them disappear from the web. Furthermore, Green OA arrangements that allow authors to deposit their manuscripts in a public repository of their choice after 12 months not only expands the range of possible ways a review

may be accessed, but also increase the risk of a largely disseminated knowledge base across vulnerable portals and sites. Arrangements with these sites are vital to ensure that published work is available both now and in the future.

We conclude that there is a problem with quality of the reviews and that addressing this problem is top priority for sustainability of Cochrane. The second priority, also important for sustainability, is to widen access to the reviews. And the third priority is to ensure that the record of knowledge produced by Cochrane is permanent.

Managing the resource

In addressing these three priorities Cochrane will need to turn attention to its own attributes and processes, especially understanding the resource, the nature of the interactions in its own entities, and the production of public goods with emphasis on rules and governance.

The task is to manage the resource to achieve the goal(s) in a sustainable manner. The resource for this knowledge commons is complex and relies to a significant extent on all three main sources – social capital, human capital and funds. The actual mix has probably varied significantly over time and with the nature of the task. Most information about the first decade of Cochrane, and particularly the early years, indicates that social capital was an important resource. There are some indications that the importance of social capital in the mix has been reduced in the second decade as the excitement, enthusiasm and commitment that marked the early years has waned. Some have argued that there is less social capital now than before and that the amount being created today is less. It is also possible that at the specific group level social capital is being built through interactions around specific tasks.

Thus, whilst the role of social capital is agreed to be important, its role has not received explicit attention and measurement is difficult. Nevertheless, many believe that it remains an important resource component. If so, it will be important to continue to build social capital now.

Cochrane has been heavily reliant on human capital from the start, and continues to have access to highly qualified academic, technical and administrative staff, both in the various groups and at the central level in a range of countries. This is one of the most important resources for Cochrane. The extent to which this component of the resource is dependent on a certain level of social capital is thought to be significant but so far has received no attention in Cochrane.

It is also important to remember that authors who publish in peer-reviewed journals do so without payment – what Suber (2011) describes as ‘author donation’. Their motivation for doing this is that they want their work to be ‘... noticed, read, taken up, built upon, applied, used and cited’. In addition, they use the journal’s time stamp to establish when the work was done, and they use this method of publication to advance their careers. Scholars can donate their journal articles because they are paid by universities and hospitals. Assessing Cochrane depends on understanding these underlying motivations.

The category of personnel in shortest supply, relative to need, are the Co-ordinating Editors (CEs) – they are usually among the most senior and experienced people in their field, often have a heavy workload in their regular job, and usually bear responsibility for mentoring and supervising more junior staff working on CRs and for signing off on the protocols and reviews issuing from their group. There are some

indications that where this does not happen the quality of reviews is lower. Further, as CEs are usually the oldest group of Cochrane volunteers they are the ones most likely to leave due to retirement. Now is the time to start finding their replacements, to start succession planning.

It is our observation that the CEs are frequently the point at which congestion in the editorial process occurs – they are also the people most likely to be able to ensure that younger participants have a positive experience. Recruiting more authors and more reviews will increase, rather than decrease, congestion at the CE level. On the other hand, support for the CE would potentially ease their workload, ease congestion, facilitate improved quality of reviews, allow identification of the next generation of CEs, and enable a smoother succession.

Thus, managing the resource in all its complexity (social, human and financial) is critical to the sustainability of the Collaboration; failure to do so will lead to degradation of the resource and, ultimately, to reduced ability to meet its goals.

Collective action problems

Like all group efforts, Cochrane is subject to the collective action problems of free-riding, variable commitment, and under-supply of public goods, especially surveillance of its product, compliance with rules, and processes for dispute resolution.

Improving quality, access and permanence requires attention to the internal processes of Cochrane, especially rules-in-use and overall governance, surveillance, and conflict resolution, all areas that appear to have been under-emphasised and under-provided in the past. Correcting this under-provision will be more likely if there is clear endorsement by the CCSG, and clear and deliberate support by the senior members of Cochrane.

It seems clear that there is considerable variation between CRGs, and possibly groups of authors, in the rules-in-use during the production of CRs. Whilst the MECIR standards have been set, there is still considerable variation between groups in editorial process; this includes variation in the core rules-in-use by authors and CRGs. For example, only in 2017 is the organisation agreeing that reviews that do not meet basic quality criteria can be rejected, and yet by June 2017 the 'rejection policy' has not been agreed. The task now is for the CRGs and other entities to agree anew on the basic rules-in-use that should form the core of Cochrane processes in all CRGs as reviews are produced. Similar attention is required to identify the basic rules-in-use that govern processes at the CCSG level. It is vital that at all levels the emphasis is on transparency and accountability.

Surveillance of quality and public disclosure of the results is critical to improving quality of the reviews. Systematic surveillance of quality has been missing from the Cochrane toolkit from the beginning. This, combined with the belief that they had the best quality in the business so there was no need for surveillance, meant that variation was not detected until after the event and, even then, there was no public disclosure of the results. Both surveillance and disclosure (and the discussion that, hopefully, ensues) are now needed if Cochrane is to justifiably reclaim the mantle of the highest quality systematic reviews.

Public discussion of the results of such surveillance will mean that there are disputes and conflict over quality and the best way to improve it. It may require withdrawal of commission from some CRGs and CEs. There will then be a need for agreed

procedures for conflict resolution, something that has apparently also been missing from the Cochrane toolkit, probably because conflicts have mostly been avoided or dealt with in non-transparent ways in the past.

Cochrane needs to look more closely at processes and interactions within its entities. These interactions are the crux of Cochrane activities, but little seems to be known about how these entities operate and the ways in which they might be strengthened. This will involve understanding the motivations of the members and the ways in which engagement of this volunteer force and the quality of their product can be improved and sustained. This understanding is essential to controlling free-riding and enhancing commitment.

Finally, the Cochrane community will need to address the difference in interests between the volunteers who produce most of the output, and the salaried staff. The volunteers are motivated to produce reviews with the widest possible access and use, and have a strong interest in maintaining quality. Whilst they have interest in a publishing model that at least breaks even, their interest in a profit is much less marked. At the same time, the salaried staff necessarily have interest in a publishing model that turns a profit, at least sufficient to provide regular increases in salary, even if at the expense of access and future use. In addition, there are tensions between various constituent groups, for example Cochrane Centres, aiming to get authors in the region published, and CRGS, who, in recent years, may reject author teams if they do not seem to have the required skills to complete a review; or between software development teams aiming to produce next generation platforms and authors and editors struggling to complete high quality reviews using platforms with bugs that are not being fixed due to these other commitments. These fundamentally different interests need to be recognised, understood and, if possible, accommodated or resolved.

Running in parallel with differences in interests between volunteers and salaried staff is the issue of centralisation and decentralisation of Cochrane. It started as a very decentralised organisation with a small staff and a basic set of rules-in-use. Now, what are essentially commercial concerns, deriving from the business model and publishing agreement, are pushing Cochrane in the direction of more central staff and increased control from the centre. Whilst some movement in that direction may be required there is increased tension between the periphery (for instance, CRGs) and the centre as the search for future direction continues. Finding the balance between control by the centre, discretion at the periphery, and support for and from the producers is a critical and ongoing discussion for all organisations, including Cochrane, as they change, their environment changes, and their resources change as well.

Competing interests

Paul Garner helped establish the Cochrane Collaboration, contributing to the first Colloquium in 1993. He is a co-ordinating Editor of the Cochrane Infectious Diseases Group, was part of the Editorial Executive that built the case for the Editor in Chief, and has been a longstanding advocate for better quality and that the collaboration should be challenged.

Peter Heywood has viewed Cochrane from afar since its inception. His current interests are in institutional analysis of knowledge commons. He declares no competing interests. Anne Marie Stephani was employed through a grant to the Liverpool School of Tropical Medicine and Paul Garner as a full time Managing Editor of the Cochrane Infectious Diseases Group.

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Notes

¹ <http://community.cochrane.org/editorial-and-publishing-policy-resource/cochrane-review-management/policy-withdrawing-published-cochrane-reviews-including-protocols>

² <http://community.cochrane.org/editorial-and-publishing-policy-resource/cochrane-review-management/process-event-serious-errors-published-cochrane-reviews>

References

- Central Editorial Unit (CEU) 2015, *Audit of published new Cochrane Reviews of interventions: 2014 Target 1.2*, Cochrane Collaboration
- Chan, L, Costa, S, 2005, Participation in the global knowledge commons, *New Library World*, 106, 141–63
- Cochrane, 2009, *The Cochrane Collaboration: A strategic review, recommendations report*, The Cochrane Collaboration
- Cochrane Collaboration, 2014, *Cochrane organisational policy manual*, Cochrane Collaboration
- Cochrane, AL, 1972, *Effectiveness and efficiency*, London: Nuffield Provincial Hospitals Trust (Reprinted in 1989 in association with *BMJ*)
- Creative Commons, 2015, Which Creative Commons licence is right for me? <http://creativecommons.org.au/learn/fact-sheets/licensing-flowchart>
- Frischmann, BM, Madison, NJ, Strandburg, KJ, 2014, *Governing knowledge commons*, New York: Oxford University Press
- Hess, C, Ostrom, E, 2011, *Understanding knowledge as a commons: From theory to practice*, Cambridge, MA: MIT Press
- Klein, M, Van de Sompel, H, Sanderson, R, Shankar, H, Balakireva, L, Zhou, K, Tobin, R, 2014, Scholarly context not found: One in five articles suffers from reference rot, *PLoS One* 9, e115253
- Misso, K, Kleijnen, J, Aldersen, P, Aubin, J, Cairns, J, Crowe, S, Garner, P, 2017, Evaluation of NIHR investment in Cochrane infrastructure and systematic reviews, National Institute for Health Research, University of Southampton, www.journalslibrary.nihr.ac.uk/downloads/other-nihr-research/evaluation-of-NIHR-investment-in-cochrane/NIHR_Cochrane_Report_Feb_17.pdf
- Olsen, O, Middleton, P, Ezzo, J, Gotzsche, PC, Hadhazy, V, Herxheimer, A, Kleijnen, J, McIntosh, H, 2001, Quality of Cochrane reviews: Assessment of sample from 1998, *BMJ*, 323, 829–32

- Ostrom, E, 1990, *Governing the commons: The evolution of institutions for collective action*, Cambridge: Cambridge University Press
- Ostrom, E, 2011, Background on the institutional analysis and development framework, *Policy Studies*, 39, 7–27
- Smith, V, Clarke, M, Williamson, P, Gargon, E, 2015, Survey of new 2007 and 2011 Cochrane reviews found 37% of prespecified outcomes not reported, *Clinical Epidemiology*, 68, 237–45
- Strandburg, KJ, Frischmann, BM, Cui, C, 2014, The Rare Diseases Clinical Research Network and the Urea Cycle Disorders Consortium as a nested knowledge commons, in BM Frischmann, MJ Madison and KJ Strandburg (eds), *Governing knowledge commons*, New York: Oxford University Press
- Suber, P, 2011, Creating an intellectual commons through open access, in C Hess and E Ostrom (eds) *Understanding knowledge as a commons: From theory to practice*, Cambridge, MA: MIT Press
- Waters, DJ, 2011, Preserving the knowledge commons, in C Hess and E Ostrom (eds) *Understanding knowledge as a commons: From theory to practice*, Cambridge, MA: MIT Press
- Wilsdon, J, Allen, L, Belfiore, E, Campbell, P, Curry, S, Hill, S, Jones, R, Kain, R, Kerridge, S, Thelwall, M, Tinkler, J, Viney, I, Wouters, P, Hill, J, Johnson, B, 2015, *The metric tide: Report of the independent review of the role of metrics in research assessment and management*, London: HEFCE