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Wouters, P.F.

Publication date
1997

Published in
Scientometrics

[Link to publication](#)

Citation for published version (APA):

Wouters, P. F. (1997). Citation Cycles and Peer Review Cycles. *Scientometrics*, (38), 39-55.

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CITATION CYCLES AND PEER REVIEW CYCLES

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(Received October 3, 1996)

Hardly anyone will dispute that the creation of the *Science Citation Index* has made an important difference to science. It is less clear, however, in what way the science system has been influenced. This article proposes a qualitative model to better understand the mutual interactions involved. Science is pictured as an information processing cycle. Its quality is maintained in the "peer review cycle". The main upshot of the *SCI* has been the creation of a second-order cycle on top of the primary knowledge production cycle. This is the citation cycle. The specialty of scientometrics has a key role in this citation cycle. The model enables a more profound understanding of the various feed back processes between the two cycles. Moreover, it may give insight in the development of hybrid and heterogenous scientific specialties like scientometrics.

1. Introduction

The metamorphosis of the modern research system is currently being discussed by science policy students (Cozzens et al.¹). There is no agreement as to the extent and character of the transformation involved. Consequently, different terms, indicating various analytical and political perspectives, have been used. The phenomenon is typified as "science in a steady state" (Ziman,² Ziman³), "mode II in the production of knowledge" (Gibbons et al.⁴), "epistemic drift" (Elzinga⁵), "the triple helix" (Leydesdorff and Etzkowitz⁶) and "a post-modern research system" (Rip⁷). The general feeling of these authors can be summarized in the words of Gibbons et al.⁴:

The transformation of knowledge production (...) is one of the central processes characterising the societies of the advanced industrial world. Knowledge production is less and less a self-contained activity. It is neither the science of the universities nor the technology of industry, to use an older classification for illustrative purposes. Knowledge production, not only in its theories and models but also in its methods and techniques, has spread from academia into all those institutions that

seek social legitimation through recognisable competence and beyond. Science is less the preserve of a special type of institution, from which it is expected to spill over or spin-off to the benefit of other sectors. Knowledge production is increasingly a socially distributed process. Moreover its locus is global, or soon will be (*Gibbons et al.*,⁴ p. 156).

The assertions of a qualitative change in the science system remain rather speculative, however. It is not yet clear in precisely what way, at what level, on which scale and in what tempi science is shifting in a new mode. Specific elements of the supposed transformation have been corroborated by empirical research indeed (e.g. *Slaughter and Rhoades*⁸). *Hicks and Katz*⁹ confirm a trend towards much more inter- and multi-disciplinary research. They find less proof for a general shift to application oriented research. One may enumerate the following areas where qualitative changes may be expected (see also *Ziman*¹⁰):

1. research funding and science policy (discourse);
2. public understanding of science and science journalism;
3. function of the scientific instrument;
4. problem selection;
5. role and building of institutions;
6. scientific communication;
7. science evaluation.

Whether this adds up to a systemic transformation is, however, an open question. In this paper, I wish to focus on the last domain of the hypothetical transformation in science: science evaluation. Since recognizing transformations presupposes a theory to validate one's empirical findings with, I propose a qualitative model to understand the mutual interactions involved. In this, I build on two older concepts: the citation cycle and the knowledge production cycle.

2 Theoretical concepts

*Price*¹¹ was one of the first to model the growth of science by exponential and logarithmic functions. *Price*¹² also coined the term "citation cycle". He wished to

exhibit an interlocking metabolic complex of bibliometric (and scientometric) parameters in a comprehensive and integrated structure after the manner of the Nitrogen Cycle (*Price*,¹² p. 621).

Price's citation cycle follows the construction of the science citation index itself. It tries to quantify the relationships among such items as source authors, cited authors, source publications, citing and cited articles. Notwithstanding Price's witty and clever text, it is not exactly clear what the citation cycle consists of. It is more of a tourist streetcar route – illustrating various aspects of the structure of science – than a metabolic cycle.

The citation cycles proposed in this article are somewhat different. They are dynamic cycles. They process and generate specific information about science. The citation cycles are therefore based on primary processes of scientific knowledge production. They are second-order phenomena. Scientometrics plays a key role in these citation cycles.

*Latour and Woolgar*¹³ modelled scientific knowledge production as a credibility cycle. Scientific credibility functions in their model like symbolic capital. It enables the transformation of material goods and money into research resources. These resources are subsequently used to generate scientific facts and results. These results generate credibility for their creators, if the peers value them. Credibility enables the researcher to enter the next cycle, because it provides her with good opportunities to acquire new funding. Thus, this cycle generates credibility on a potentially growing scale. Knowledge production is in principle, if not in practice, an endless cycle.

I propose to combine and transform these two key concepts of the knowledge production cycle and the citation cycle. This recombination creates a partially new picture of the interaction between scientific knowledge production and evaluation. Moreover, it provides for a novel perspective on the development of scientometrics as a (social) scientific specialty. In science studies, several models have been proposed to describe specialty development (e.g. *Mullins*,¹⁴ *Mullins*,¹⁵ *Mullins*,¹⁶ *Lemaine et al.*,¹⁷ *Mulkay et al.*,¹⁸ *Edge and Mulkay*,¹⁹ *Johnston and Robbins*,²⁰ *O'Connor and Meadows*,²¹ *Shrum*,²² *Sullivan et al.*,²³ *Studer and Chubin*,²⁴ *Small and Griffith*²⁵). The various models applied in these studies vary in their scope, methods and data construction. Nevertheless, they suppose the specialty to have a clear-cut identity at the substantive (social or cognitive) level. Whether based on shared social relations, a set of journals, interlocking funding mechanisms or problem formulations, the specialty can be localized. Its identity may change in the course of specialty growth. Nevertheless, its boundaries do not disappear.

This type of specialty study does not seem so attractive any more. First of all, newly developing specialties in the sciences, the social sciences and the humanities display extensive hybrid characteristics. They are no longer "purely academic" or "purely industrial". On the contrary, they appear to include intensive interactions between

universities industry, and society (Etzkowitz²⁶). Moreover, multi- and inter-disciplinary research is fast becoming the rule instead of the exception (Gibbons et al.,⁴ Hicks and Katz⁹). This tends to diminish the relevance of studies focussing on mono-disciplinary specialties. Thirdly, even within supposedly homogenous academic specialties, researchers have been shown to address quite different contexts in their research (Knorr-Cetina²⁷). This finding has led to notions of "heterogenous engineering" (Callon²⁸) and "transepistemic fields" (Knorr-Cetina²⁹). Consequently, the scientific specialty more or less disappeared from the stage of exciting concepts in science and technology studies. Seen from this perspective, the specialty studies of the seventies seem rather naive with regard to the social forces shaping scientific knowledge. One could even doubt the very existence of scientific specialties.

Yet, the specialty still plays an important role. Scientific researchers are trained within the boundaries of a certain specialty. The level of the specialty and the discipline are crucial to the integration of various puzzles into consistent bodies of knowledge. Most scientific conferences are specialty-specific phenomena. How can these experiences be made compatible with the findings of science studies?

A solution to this particular problem might be to hypothesize the specialty as the unit of analysis at a higher level of abstraction. Its identity may not be found as a property at the substantive level (social or cognitive) in the first place. It might be the difference between the way it represents its object of study and other, competing, representations that counts more. The dynamics of scientific specialties may then be explained in terms of the interaction of these differences with social and cognitive processes at the substantive level. The observed cognitive and social phenomena may, in other words, be interpreted as the projections of these interactions in the substantive level. Specialty development may then be a specific instance of the evolution of systems of references of social systems (second-order dynamics) (Leydesdorff,³⁰ Luhmann³¹).

Scientific knowledge is in this article taken to be a specific representation of an object. The production rules are more or less clearly defined. They are the product of elaborate social and historical processes. Knowledge production is a recursive process: most study objects are themselves scientific or technological representations. This view is relativistic, since there does not exist any firm ground for a definitive theory of truth. At the same time, this approach allows for the specific study of science. Although science is socially constructed, it is still different from other social constructions like religion. In other words, this approach allows for the use of the concept of scientific truth.

By representation I mean a structure, i.e. a material device or non-material phenomenon, which is created by using a specific selection of elements of another phenomenon in such a way that it can be used as stand-in for that phenomenon. I take it that a phenomenon can only be known through its representation by an observer (*Lynch and Woolgar*,³² *Maturana and Varela*³³). Every representation is the product of some interaction of the phenomenon it represents, which is its object, with its own production rules. The terms representation and object presuppose each other: the object is not the underlying hard reality causing the representation, it is merely that which is represented.

A representation does not have to be "isomorphic" to its object in some absolute sense. If the representation aims to represent the internal structure of the represented object, its organization will be isomorphic to the organization of its object according to criteria specified by the observer. If, conversely, it aims to represent the object's action or function it will behave isomorphically, again according to the observer's criteria. Whether or not the representation represents its object well, depends solely on its function. Although it is by definition impossible to compare object and representation directly, one can compare representations among one another. Moreover, one can study the production of representations reflexively or produce new ones practically (*Hacking*⁴). "Knowing the object" can be represented as nothing else but the result of these operations. And the resulting knowledge is itself a new representation of the phenomena involved. Knowledge is by definition embedded knowledge (*Haraway*,³⁵ *Geertz*³⁶). Thus, what counts is the difference between various representations. This difference is, however, not directly observable nor does it function like a final cause. The import of representational difference embodies itself only at the more concrete substantive level. The abstract level of representational difference can be interpreted as a domain of possibilities, that need not be realized. Hence, mapping this domain with respect to a specific specialty may lead to the exploration of possible future trajectories.

3. Peer review cycles

Knowledge production can be analyzed as a cyclical process in which certain inputs, like money and labour force, are stepwise translated into certain outputs, like scientific articles and knowledge claims. The various steps have been thoroughly analyzed in science studies. Scientific knowledge is systematically evaluated. This assessment is subsequently used in the setting of new targets and the writing of new research proposals. Figure 1 gives a schematic overview of this cycle.

Fig. 1. The peer review cycle

If we, arbitrarily, start the description of this cycle with the writing of a research proposal, the second step is its evaluation by the peers involved (using both scientific and extra-scientific criteria). The research is then being taken up, possibly leading to a submitted article. A second form of peer judgement produces, if positive, an article. At regular intervals, research groups, university institutions and specialties are being assessed. These evaluations at higher levels of aggregation are again based on expert judgement, and constitute the third form of peer review in this cycle. The results of these diverse evaluations contribute to the process of priority setting, ultimately leading to new proposals.

As can be seen, peer review is central in this cycle. This does not mean, of course, that peer review is some uniform phenomenon. On the contrary, it has been shown to vary widely in the scientific communities (*Chubin and Hackett*³⁷). I do not mean to state, either, that science would cycle in one single peer review cycle. The peer review cycle shown in Fig. 1 is an abstract representation of the multitude of peer review processes taking place in scientific and technological research. The different phases of this cycle are not always executed and they may take various forms in different countries. This peer review cycle itself is the product of a rather complex and convoluted history. It should not be seen as science in its purest form, since it is itself heavily influenced by science policy considerations in the past (*Rip*³⁸).

The scheme does represent, however, important properties of the knowledge production at a general level. It reduces science's complexities to one dimension, information processing. In representing science in this way, we take information as the entity that flows and as the substance that is translated in various forms during this cycle. It can easily be seen that this peer review cycle is in no way autonomous. For example, political priorities influence the step from evaluation to priority setting and to a growing extent also the peer judgements of research proposals by research councils. Monetary and economic arguments influence the overall science budget. And the peer judgements as well as the formulated scientific problems are contingent on culture at large. Nevertheless, the scheme shows the central position of scientific expertise in the validation of scientific knowledge. The evaluation of the state of affairs in science is predominantly founded on the digestion of the cognitive products of science, as laid down in the scientific literature.

4. Citation cycles

This is changed by the bibliometric output indicators. Since their advent, a scientific publication can be measured with citation analysis. It claims to gauge the influence, impact or quality of the scientific production. Hence, no longer is the expert in the field the sole source of evaluation expertise. If we continue to represent science as an information producing and transforming cycle, the bibliometric indicators appear in the form of extra cycles. These cycles process information about the primary information cycles. As is well-known, two different notions of information exist.

The first is formulated by *Shannon and Weaver*³⁹ as the minimum amount of coding necessary to transmit a message over a communication channel. This definition (dominant in information science) abstracts from the meaning of the message. The second definition of the notion of information is formulated by *Bateson*.⁴⁰ According to *Bateson*, information is "the difference that makes a difference". This information notion puts the meaning of the message to the fore, not the way of sending it. However, neither of these two definitions make any difference between information and information-about-information. Hence, the second-order cycle is an information cycle, like the primary.

Contrary to the first, the second-order cycle does have a distinct beginning. This is the consequence of its contingency on the primary information cycle. Its first step is the semiotic inversion of the reference into the citation (*Wouters*⁴¹). This step needs some more explanation, because of the still existing confusion regarding the difference between the reference and the citation. At first sight, the field of scientometrics seems

perfectly aware of the difference between a reference and a citation. *Price*⁴² underlined this as well as *Narin*⁴³ and *Egghe*. However, this distinction is commonly interpreted as a merely technical difference. It seems hardly relevant for anyone but the inherently meticulous:

If one wishes to be precise, one should distinguish between the notions 'reference' and 'citation'. If paper *R* contains a bibliographic note using and describing paper *C*, then *R* contains a reference to *C* and *C* has a citation from *R*. (*Price*⁴²).

Stated otherwise, a reference is the acknowledgement that one document gives to another, while a citation is the acknowledgement that one document receives from another. When authors expand on the distinction between reference and citation, they mostly focus on the different characteristics of the distributions of references and citations. For example, *Gilbert* and *Woolgar*⁴⁴ point to this:

In a growing field, the characteristics (such as the average age and number) of the references in a paper will not necessarily be the same as those of the citations to a paper. The work of some studies is confused by giving both citations and references the same name.

Leydesdorff and *Amsterdamska*⁴⁵ use this difference to reconstruct both as indicators of different systems of reference. Reference analysis would inform us about "action" while citations are indicative of "structure". However, since these distributions of references and citations are not the topic of most scientometricians, the distinction *Price*⁴² refers to is glossed over most of the time. Now, the crux of the matter is that the difference between the reference and the citation is neither merely technical nor only of interest in relation to distributions of references and citations. On the contrary, it relates to the heart of citation analysis and, since citation analysis has a central position in the whole of scientometrics, of the latter as well.

I wish to draw attention to the consequence this difference has for the relationship of science and technology indicators with scientific knowledge production. The reference is always an attribute of the citing article, whereas the citation is a property of the cited document. Each time a reference is processed by citation indexers, it is transformed into a citation. In semiotic terminology: the reference has the citing article as its external reference. The citation, on the contrary, has the cited article as its external reference. Hence, both signs are different. In focussing on the construction of science and technology indicators it is therefore imperative to place this semiotic inversion at the core of the analysis. It is the first and decisive step which creates the citation cycles.

On the basis of this first step, more elaborate citation indicators are being built in the citation cycle (see Fig. 2). In successive steps relative citation frequencies, co-citation indicators and maps of science are being produced. Interestingly, the citation cycles also have a secondary entry. Parallel to the semiotic inversion of the reference into the citation, the word can be transformed into the keyword. This is the basis for co-word analysis, which combines at the top of the citation cycles with citation analysis to produce maps of science.

Fig. 2. The citation cycle

If citation analysis were simply a numerical mirror of peer review judgements, nothing much new would be happening. This is, however, not the case. The translation of references into citations creates additional degrees of freedom in handling citations. This is enhanced by the construction of more elaborate indicators and maps, all of which implicate numerous more or less arbitrary decisions. This does not mean that "anything goes", at least not as good as any other thing. It does mean, however, that functionally equivalent indicators can be made in several ways. For example, the importance of scientific journals can be weighed with various impact factors (Moed et al.⁴⁶).

The main results of the citation cycles are representations of science:

1. in the form of information about the performance of researchers, research institutions or other actors in terms of certain indicators;
2. in the form of maps of science;
3. and in the form of ratings of, e.g., journals in terms of impact factors.

It is crucial to keep an eye to the difference between the primary and the second-order information cycle. The peer review cycle is based on the intellectual content of the literature (which is itself a specific representation of the research results). The second cycle is based on formal information about this information, purposely neglecting the intellectual content of the scientific literature.

5. Interacting cycles

In order to find out how the two distinct information cycles influence one another, let us first distinguish the various possible interactions.

The following possible interplays between the two cycles may occur (see Fig. 3):

1. the indicators may influence the evaluation of science directly. This is for example the case whenever the citation frequency is used as a measure of scientific performance;
2. the indicators may redefine the notion of quality in the realm of peer review judgements. This may happen if writing sound publications is in itself not enough to earn, say, a tenured position. An extra item on the curriculum vitae, like visibility in the ISI covered journals, may be necessary;
3. the constructed maps of science (and other complicated science representations) may alter the evaluation process. These maps may for example turn upside down the mental map of scientific experts judging a certain sub-specialty;
4. scientific experts may be involved in the validation of co-citation and co-word maps. Since the maps involved are highly sensitive to the thresholds used at different stages in the computational process, the used measures and their resulting maps may be fine-tuned to produce images that make sense to experts in the field. These validated maps may subsequently be used in follow-up analyses;
5. scientists may also be involved in the validation of ranking lists. It is imaginable, for example, that experts can pinpoint anomalous ranking phenomena, if only because they know the people on the list (contrary to the scientometrician);
6. scientific experts may be directly involved in the construction of quantitative indicators. They may, for example, be used as a source of expert knowledge on specific features of the scientific literature involved.

Fig. 3. Interactions of peer review and citation cycle

All six possible forms of interplay between the two information cycle have in common that they entail a translation of one type of science representation into another. In Fig. 3, the upper right half represents the domain of the citation cycle with its formal representation of the scientific literature. The lower left half represents the domain of the peer review procedures with their stressing the cognitive dimension of science. Since meta-information cannot be distinguished, in itself, from information, the two cycles may interact easily. Policy tends to promote this interplay. This means that the two cycles will tend to change the very foundation on which they are built. In other words, neither of the two can easily be found in their pure form with empirical means. Consequently, influence from the one on the other will tend to go unnoticed at the substantive level.

If realized, these interactions may influence the scientific system both at the level of the individual scientist and at the level of science policy. First of all, the evaluation of science may now get two different kinds of input: one representing the conclusion of the field specific experts and one representing the scientometric expertise. Because of this, the field-specific scientist no longer has the monopoly position in evaluating science. The two different forms of evaluation do not have to be distinguishable in any clear-cut fashion. The various interactions mentioned above, will on the contrary promote the blending of the two perspectives. Nevertheless, they represent analytically different science representations. These differences will create both the space and the need for negotiations and mutual validations between the expert opinion of the scientists

peer review cycle takes place as well, although this seems to be the more controversial affair. The record of evaluating specialties and disciplines gives a rather mixed picture. For example, the various "foresight committees" in Dutch science policy have taken a rather different attitude towards the inclusion of quantitative and bibliometric indicators (*van der Meulen*,⁴⁷ *van der Meulen*⁴⁸). The inclusion of citation data in the assessment of the performance of individual scientists is even more controversial. Nevertheless, the fact that these interactions take place, can hardly be denied. The question whether the emergence of the citation cycle has fundamentally changed the notion of scientific quality in any fundamental way is an important empirical question. One would expect this to be the case indeed.

Even if the concept of quality should not have changed, however, the emergence of the citation cycle is a significant phenomenon in the scientific system. It constitutes an extra (meta)information cycle. As a consequence, science produces two analytically different self-representations. One is the domain of the expert in the field, the other the prerogative of the scientometrician. Since the systematic validation of knowledge claims is a central axis around which the wheel of science spins, the citation cycles affect vital parts of scientific knowledge production. It seems rather strange, then, to neglect science and technology indicators in the discussion of the research system's future. Admittedly, information cycles are rather elusive features. Given their nature as hypothetical constructions, they cannot be proved or disproved directly. Nevertheless, the citation cycle has led to such material phenomena as a permanent controversy on the use of indicators, the specialty of scientometrics, the journal *Scientometrics* and lately even an international society, the International Society for Scientometrics and Informetrics ISSI. In other words, the citation cycle has affected both the institutional structure of science and the discourse on science evaluation. With the notion of the information cycle and the citation cycle, these various developments can be analyzed in one consistent framework.

6. Conclusion: scientometrics as a specialty

Analyzing science as an information cycle enables the integration of two divergent bodies of literature: one focussing on science and technology indicators as policy instruments, the other focussing on the development of scientific specialties. If we see the production of scientific knowledge as the processing and generation of information, scientometrics is one of the second-order information sciences, producing specific information on information. As said, since the creation of the *Science Citation Index*, a new sign system on science has emerged. The evolution of scientometrics has been

driven by both the exploration and exploitation of this new sign system (a pushing mechanism) and the market for science and technology indicators (a pulling mechanism). This is the main reason for the dominant position citation analysis occupies within the range of possible measurement techniques. Its power lies in its capacity to represent the whole of science including policy interventions in the scientific realm. The overall buildup of scientometrics can be analyzed as both the unfolding of the potentials of this statistical language and the creation of novel relations with the peer review cycle, i.e. with the production of scientific knowledge. This process can be seen as a mutual calibration and standardization. No one scientometric group has determined this overall process. On the contrary, the development of scientometrics is a blind co-evolutionary process in which the scientometric research groups compete with one another on the market for indicators on top of the academic competition for reputation (*Wouters and Leydesdorff*⁴⁹). This may be the cause for the fact that each scientometric research group has developed its own set of methods and techniques. Until recently, hardly any common standards existed in the field. Recently, however, a new development has set in. Now that the main quantitative techniques of citation and co-word analysis have been explored and built up, a diversification of methods per group appears (e.g. *Moed et al.*⁴⁶) and the need for standardization emerges (*Glänzel and Schoepflin*⁵⁰). This development has indeed set in at the recent international meeting of scientometricians (ISSI 1995, Chicago). From the perspective of this paper, these events can be understood as signifying the end of the extensive development of the citation centered sign system and the transition to an intensive development. In this new stage, present indicators can expect to change and blend with other indicators, especially econometric ones.

This seems to go hand in hand with the emergence of new forms of meta-information about science. Scientometricians are not the only actors on the stage of science evaluation, nor the most important ones. Both formal methods (computerized full text analysis, factor analytical bibliometrics, network analysis), meta-analysis as well as complex management tools are being developed to run the scientific enterprise. As a consequence, scientometrics as a separate entity might very well disappear. It may become part of information science, and more specifically of those information sciences which produce information about information. As a consequence, bibliometric indicators and scientometrics may appear to become less central on the stage, even if used more frequently. They have, however, left their mark in the emerging new information processes in the production of knowledge.

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