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THEORIES OF CITATION ?

L. LEYDESDORFF

Science and Technology Dynamics, Nieuwe Achtergracht 166, 1018 WV Amsterdam
(The Netherlands)

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'By now, it may seem redundant to say
that a theory of citation is badly needed.'
Zuckerman (1987)[95]

Citations support the communication of specialist knowledge by allowing authors and readers to make specific selections in several contexts at the same time. In the interactions between the social network of (first-order) authors and the network of their reflexive (that is, second-order) communications, a sub-textual code of communication with a distributed character has emerged. The recursive operation of this dual-layered network induces the perception of a cognitive dimension in scientific communication. *Citation analysis* reflects on citation practices. Reference lists are aggregated in scientometric analysis using one (or sometimes two) of the available contexts to reduce the complexity: geometrical representations ('mappings') of dynamic operations are reflected in corresponding theories of citation. For example, a sociological interpretation of citations can be distinguished from an information-theoretical one. The specific contexts represented in the modern citation can be deconstructed from the perspective of the cultural evolution of scientific communication.

1. Introduction

Citation analysis has been a formative instrument of scientometrics as a subject of study for several decades. The primary impulse to organize citations into a *Science Citation Index* came, however, from information retrieval. *Garfield* was inspired by the American system of legal documentation.[26, p.7] In an early phase, *Price* joined the citation project: he associated the data of the *SCI* with measurement techniques. Concepts like 'mapping science' by studying the dynamics of citation networks were introduced (e.g., *Price* 1965;[69] cf. *Wouters* 1998[93]).

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Notwithstanding serious attempts in this direction (e.g., *Small* 1978[77]), a complete theory of citation is still lacking. In 1981, two authors raised this problem independently, yet from different perspectives: *Cozzens* (1981)[16] provided a review of citation theories from the perspective of sociology, and *Cronin* (1981)[19] asked for a theory of citation from the perspective of information retrieval. In his ensuing monograph, *Cronin* (1984)[20] discussed citation as a function in scientific communication *among* texts. In citation context analysis (e.g., *Chubin* and *Moitra* 1975;[13] *Moravcsik* and *Murugesan* 1975[65]), the theory of citation had until then been developed mainly with reference to the uses of citations *within* articles.

Others (e.g., *MacRoberts* and *MacRoberts* 1987;[57] *Latour* 1987[42]) have drawn attention to the perfunctory and rhetorical functions of citations within the scientific community (*Cozzens* 1989[18]). Evaluation studies for science policy purposes have considered citations as an indicator of reward in the science system (*Martin* and *Irvine* 1983;[58] *Moed* et al. 1985;[64] *Luukkonen* 1990;[55] cf. *Merton* 1968;[63] *Latour* and *Woolgar* 1979[43]). Furthermore, new scientometric indicators such as 'co-words' were introduced in the 1980s (*Callon* et al. 1982[9]). While 'co-citation maps' were interpreted as representations of perceptions by citing authors (*Small* 1973;[75] *Small* and *Griffith* 1974;[79] cf. *Small* 1978[77]), co-word analysis provided us with representations of semiotic networks among these authors (cf. *Callon* et al. 1986[10]). In summary, a variety of contexts for citation analysis was proposed,[55] but a comprehensive theory of citation itself could not be formulated.[95]

The variety of indicators made scientometricians aware that citations are specific, yet they share some properties with other textual indicators. Citations refer to another word, phrase, sentence, paragraph, or title of text from the perspective of the citing article. While in the case of co-word and co-citation analysis the relation is constructed by the analyst, the citation is provided as a link between two documents by the citing author him/herself. Citation is in this sense *not* a scientometric indicator; scientometric analysis is based on a careful reconstruction of citation practices using, for example, the *Science Citation Index* as a database (*Kaplan* 1965;[38] cf. *Wouters* 1997[92]). In practice, however, the meaning of citations seems easier to understand intuitively than that of analytically defined codes in scientific texts (*Snyder* et al. 1995[80]). Furthermore, citations are an order of magnitude more specific than, for example, shared (co-)words (*Leydesdorff* 1989[45]). Citations thus seem to have specific functions in the research process (*Garfield* 1996[27]).

In this study, I argue that citations as currently understood emerged during a certain phase of the scientific development, namely in the early 20th century. The historical deconstruction of the citation in terms of interacting networks of authors and texts will

enable me to suggest a new theory of citation as a dynamic operation that allows for reduction of complexity in various contexts at the same time. The dynamic perspective of selections operating upon selections in other networks accounts for the character of citations as statistical (i.e., uncertain) indicators, for their specificity, and for their multi-contextuality. A reappraisal of existing theories of citation becomes possible, and thus an opening to the discussion among citation analysts can be suggested.

2. Analytical distinctions

Citation *analysis* itself considers the use of citations in scientific literature as a practice, and the articulation of a theory of citations has remained firmly on the agenda of scientometrics. While scientometric indicators can be defined as formal methodologies, the citation process is social, and therefore challenges the substantive understanding: under which conditions can citation be used as a measure of impact, quality, relevance, reputation, etc.? How do insights from various disciplines contribute to our understanding of the epistemological process and the working mechanism of citation in science? Why has citation as a social act held such a prominent position in the generation of knowledge? Or is this very statement a distortion with hindsight from a citation analyst's perspective (*Edge* 1979[21])?

Let me introduce some analytical distinctions. The quest for a theory of citations presumes that citations themselves should be explained. First, however, one may wish to raise the question of whether citations belong to the *explanandum* – that is, the subject to be explained – or to the *explanans* – that is, used to explain something else. If citation analysis is primarily a tool for explaining, for example, the growth of science, can then a 'theory of citation' be nothing more than a methodological reflection designed to improve the accuracy of this measurement?

In my opinion, citation *analysis* is regularly used as a tool or an indicator within an *explanans*. A lack of theoretical clarity about what is to be explained by using citation analysis is almost unavoidable if the focus is – as often happens in scientometric studies – on improving the tool without theoretical attention to the specification of the *explanandum*. A problem formulated in a policy context does not always need to be elaborated theoretically. A narrative interpretation of the mappings may suffice (cf. *Glänzel* et al. 1996[34]). Differences between mappings can be studied fruitfully as validation problems (*Leydesdorff* 1987;[44] 1989;[45] 1992;[46] cf. *Van Raan* 1988[85]).

But when one raises questions like whether citations indicate 'quality', 'impact,' 'status,' etc., one is in need of a clear definition of these concepts with reference to units of analysis. Is it the quality of an author or an institution, or the quality of articles

themselves that is implied? Is one type of mapping more suitable than another for exhibiting one or another type of quality? The functions of citations are expected to be different when different contexts or different levels of aggregation are studied (*Leydesdorff* and *Amsterdamska* 1990[51]).

2.1. Citation as explanandum

Let us first focus on 'citation' as something to be explained (*explanandum*) because this specification is an initial step toward the articulation of a theory of citation in the proper sense. What actually are citations? As noted, citations are references to another textual element, from the perspective of the citing article. In order to have citations, there must be a cited-citing pair. From a formal perspective, cited-citing pairs are *relations*. By adding a dynamic perspective, these relations can be considered as relational *operations*.

The relational operation is recursive: for example, citations may refer to other texts in which citations refer to still other texts. Thus, a network of citation relations is spanned at each moment in time and reproduced over time. The network, resulting from this repeated operation is expected to have an architecture. Therefore, citations have a *position* in a multi-dimensional space constituted by other citations. Two operations can be close in terms of position without having a relation or without sharing a common relation (*Burt* 1982[6]). An operational relation is able to function in a network because of its position. Operations are expected to be reproduced if they carry functions. Thus, one has to specify the functionality of the citation process.

The functionality is understood to be embedded in the distribution (*Maturana* and *Varela* 1980[59]). While citations can be observed as specific events, they acquire analytical meaning only in terms of distributions: why was this citation used and not another? Actually, citations occur usually in groups, that is, as lists of references. Citation analysis studies the traces of the operation of this distributed network system. Citations are then observed at the nodes of the network (that is, within texts), whereas the recursive operations at the network level remain hypotheses about their cognitive functions. One is able to reconstruct only analytically this cognitive structure, for example, in terms of an 'eigenstructure' of the network. From this perspective, the observables test the theoretically informed expectations about the network's structure, and thus, cognitive assumptions are changed or reinforced.

The operation is additionally dynamic: the distributions exhibit the patterns and structures of expectations for further operation. Thus, the process of new knowledge claims is propelled and made more precise and selective. The dynamic aspect is of the

utmost importance: even when the links of a network are stabilized – as in the case of telephone lines – the frequency of the operation over the lines can be distinguished analytically from the observable carriers. The function of citations in propelling the networks of substantive knowledge contents is different from, yet constrained by their propagation through networks of textual and social relations.

I wish to argue that this multi-dimensional network is dually layered: citations are the result of the interaction between networks of authors and between networks of their communications. Thus, the modern citation is constitutionally complex, and therefore it can function in scientific practices by indicating both the cognitive and the social contexts of a knowledge claim. At a generalized level, citations, as potentially repeated operations, sustain communication in the sciences by drawing upon cognitive and social contexts.

The scientific publication which makes the citation can then be considered as an event: each publication potentially redistributes citation patterns, although the change in the overall distributions may be marginal. Thus, the subtext of a communication pattern can be communicated in a complex way among networks of authors and texts. Citations, however, are neither a necessary nor a sufficient condition for scientific communication. While nowadays they help to sustain the communication, the process of their codification has varied across fields of science (*Price* 1970[72]). Ctations did not emerge historically with scientific literature at the time of the scientific revolution. They emerged from the specific organization of the sciences in the late 19th century.

Of course, authors have always made references. The scholastic tradition of the Middle Ages, for example, can be typified by its tendency to comment on previous generations of authors (especially, Aristotle). The reference implies an implicit citation, but these citations were not to contemporary colleagues with whom one could dispute the interpretation of a text; the reference was rather to the text under discussion. In a religious society of the monotheistic type, every text is essentially a further explanation of the original text, like the Bible or the Koran. Thus, scholastic authors had to legitimate their contributions within their tradition (e.g., *Weinberg* 1997[87]).

In modern sciences, references have a different function. A new knowledge claim adds to the scientific literature by drawing a further distinction (*Luhmann* 1990, pp. 75 ff.[54]). Some citations serve to indicate where and when a new distinction can be drawn, and may indicate how such a knowledge claim can be reintegrated into a body of theorizing. Because of the recursivity involved, citations exhibit the collective character of scientific achievements at each moment in time. At the time of the scientific revolution, Newton expressed this collective character of the modern scientific enterprise with his well-known aphorism: 'If I have seen further, it is by standing on the

shoulders of giants' (*Merton* 1965[62]). These giants were scholars like Galileo, Kepler, and Huygens, with whom Newton sometimes communicated personally or in writing. Circles of correspondence among leading scientists were organized by Mersenne (1588-1648) in Paris and Oldenburg (1615-1677) in London (*Kronick* 1991[39]).

In 1665, the first volume of the *Philosophical Transactions of the Royal Society* was published, soon to be followed by the French *Journal des Sçavants.** Note that these journals were no longer published in Latin, and that they were secular publications. The circles of communication among these 'learned gentlemen' were small, and science was not yet institutionalized. Their references to one another in the texts (1665-1800) are made in the polite form of 'M. Huygens', 'Mr. Hook' or 'Signior Rizetti'. Typically, Jean T. Desaguliers comments at p. 610 of Volume 35 of the *Philosophical Transactions*:

> This must have been Signior Rizetti's mistake . . . for several of the Persons present at my Experiments made the same Mistake at first before they could perform the Experiment in manner above-mentioned.

The 'M.', which stands for 'Monsieur', is still available as a form of communication among authors in French scientific literature.

Science in the 18th century was largely based on personal communications. The 19th century witnessed the further institutionalization of science and scientific communication. For example, the *Proceedings of the Royal Society* began to appear from 1800 onwards. In Prussia's Humboldt University (after 1815) research joined education as a major function of the university. Thus, the holding of a Chair in an institute became a crucial factor for career opportunities in science. In short, science became an institutionalized social system (*Stichweh* 1984[83]).

By 1800, the codification of the legal system had provided formats for systematic and depersonalized communication: legal and material rights can be distinguished when

* The French *Journal des Sçavans* first appeared three months before the *Transactions*. Various authors still contest which nation should be accorded the honor of giving birth to the first scientific journal, with the crucial point hanging on the broader character of the French journal (*Bazerman* 1988[5, p. 129]).

natural law is formalized into positive law (*Weber*, 1922, pp. 503 ff.[86]; *Habermas*, 1981,[36] pp. 351 ff.).* Further institutionalization and growth of science during the 19th century made it increasingly possible to communicate also in this context with texts that were indicated by personal names, yet without primary reference to specific individuals. The individual scholar increasingly becomes the carrier of a knowledge claim in a network of communications among scholars. The claim itself can be debated, irrespective of the author, his or her institution, the quality of his or her *oeuvre*, etc.

During the whole 19th century, references remained firmly attributed to authors – as opposed to identifiable and precisely dated texts. *Bazerman* (1988)[5] has extensively studied the modern citation as an innovation of the early 20th century using *Physical Review* as his source material. With reference to the 1890s, he noted:

> The lack of concern with dating references, and the age of the references that are dated, further weaken the sense of a coherent, moving research front. In both 1893-95 and 1900-1901 (Bazerman's sample years, L.), 52 percent of the references are undated, and only about 30 percent are dated six years or less from the article's publication.

By 1910, the number of references per article has decreased dramatically to only 1.5, and the few references are dated and of recent vintage, suggesting immediate relevance for the work at hand. (*Ibid.*,[5] pp. 165f.)

After 1910 the number of (dated) references per article increased rapidly, and the modern citation became a specific layer of communication in and among scientific texts. The citation from then onwards can be considered as a concept-symbol (*Small* 1978[77]) instead of a reference to a person's *oeuvre* (cf. *Meadows* 1974,[60] pp. 83 ff.). In his historical exercise to construct a *Physics Citation Index*, *Small* (1986)[78] analyzed the 1920s. This is the period in which citations could for the first time be aggregated because of the further development of the modern format.

Note the novelty of the transition: the interaction between a second-order layer of reflexive communications among (first-order) authors provides the condition for the

* In 1800, Napoleon Bonaparte appointed a commission of jurors to combine all French civil laws into one code. The new codification went into effect in 1804. This 'Code Civil' represented a compromise between the customary law of northern France and Roman law of the south. It also compromised both the ideas of the French Revolution and older ideas from the south of France that used the old Roman Law. According to the Cambridge Modern History (1958),[12] 'the Codes preserve the essential conquests of the revolutionary spirit-civil equality, religious toleration, the emancipation of land, public trial, the jury of judgement. (...) In a clear and compact shape, they presented to Europe the main rules which should govern a civilised society.' (See http://www.fast-times.com/political/dictN20.html; http://www.cp.duluth.mn.us/~tmcs/CODENAP0.htm).

generation of a more abstract cognitive structure of concept-symbols. The dual-layered network system of (1) social relations among scholars and (2) relations among communications is expected to resonate dynamically on the basis of interactions in some directions, while not in others. The structural dimensions of this complex network are partially correlated to individual authors as carriers of the communication, as they are also correlated to the textual dimension of the knowledge content (*Leydesdorff* 1995[48]). The interactively emerging dimension itself remains latent while it develops, and thus a strategic vector is induced that can be recognized (cf. *Abernathy* and *Clark* 1985[1]). The recognition recursively assumes and refines cognition within the observing systems (*Maturana* and *Varela*, 1980[59]).

Over time, this operation becomes thoroughly selective on both sides: citations are sometimes 'obliterated by incorporation' (OBI) into the body of knowledge,[25] and social factors may temporarily play a role for further selections, e.g., in terms of reputations. In principle, two selective layers operating upon each other tend to extinguish the signal. However, at some places the two distributions may happen to 'lock-in' because a third (that is, cognitive) dimension can be carried further by a specific combination.

In this co-evolution between communications and authors, distributions of citations may function, among other things, as contested boundaries between specialties. Since citations are distributed, the boundaries remain to be validated (*Fujigaki* 1997[23]). Functions are expected to change when the research front moves further. By using references, authors position their knowledge claims within one specialty area or another (*Amsterdamska* and *Leydesdorff* 1989[3]). The implied social and cognitive dimensions enable practicing scientists to use citations as an instrument for retrieval. Some selections are chosen for stabilization, for example, when codification into citation classics occurs (*Small* 1974[76]; cf. *Garfield* 1979[26]). Some stabilizations are selected for globalization, that is, when 'tacit' knowledge is accepted at a super-systemic level (*Merton* 1965, pp. 218 f.[62]).

As the complex network is further shaped, citations allow for richer communications since both social and cognitive factors can be incorporated into the progression of the sciences. A reference to a codified citation provides a shorthand for not having to explain a method or another intellectual tool (*Garfield* 1979, p. 246[26]). The meaning of this reference has then become stabilized within a specific scholarly community, while intellectual and social boundaries are reinforced by readers familiar with the reference (cf. *Whitley* 1984[90]). In summary, the historical origins of the epistemological function of citation as a social practice are to be found in this distributed and dual-layered operation. The dual-layeredness of the distribution induces

the dynamics, since selections operate on selections. Yet the cognitive principle of referencing, once historically invented, had still to be diffused and then to be institutionalized.

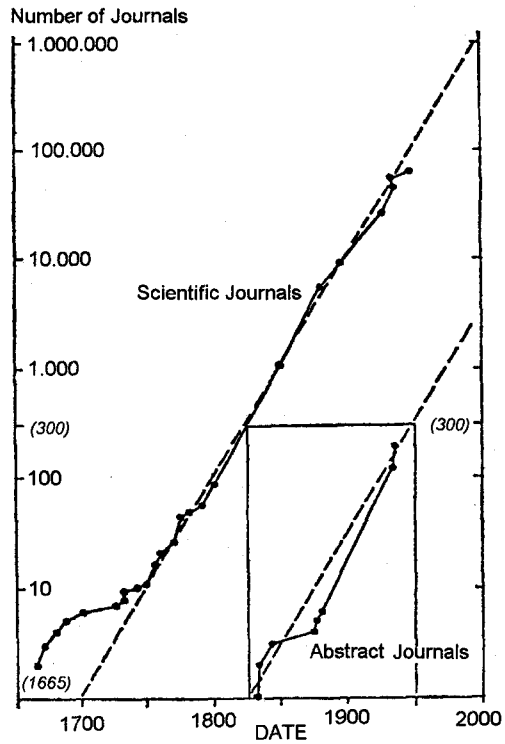

Fig. 1. Total number of scientific journals and abstract journals founded, as a function of date. From: *Price* (1961)[69]

This codification of science as a network of reflexive communications on top of a first-order network of social relations among scientists is a historical process that is also reflected in other ways. Not until the late 1960s did philosophers and historians of science like *Price* (1965)[71] and *Kuhn* (1962/1970)[40] begin to be able to understand science as an order emerging from networks of communication relatively independent of carrying authors (*Garvey* 1979[28]). *Price* (1961),[69] for example, noted the emergence of abstract journals during the 19th century as shown in his well-known graph

reproduced in Fig. 1. Once the number of scientific journals had exceeded a few hundred, higher-order codification became a condition for the further growth of knowledge. One could no longer rely on selections by individuals; networks of communication based on the interactions between people and journals ease the reproduction of the system by taking over selective functions at an above-individual level.

Social factors also have played a role in these historical transitions, like the cheaper production of paper when cotton became available to the textile industry on a large scale (*Gouldner* 1976[35]). Social contexts provide the resources for taking the next steps in the cultural evolution of the sciences (*Barnes* and *Edge* 1982;[4] *Leydesdorff* 1997[49]). The codification of science, its disciplinary differentiation (*Stichweh* 1990[84]), and its institutionalization in the Humboldt-type universities (*Jencks* and *Riesman* 1968[37]) made it necessary to develop new styles of referencing that honour science as a social enterprise and in terms of concept-symbols more abstract than authors' names. Thus, the modern citation was born as a code and a medium of communication in the early 20th century.

2.2. From citations to citation analysis

It was well into *this* century before the philosophy of science was able to achieve an understanding of 'truth' as an attribute no longer of a (personal) idea, but of a communicative statement. Citation could not be a major focus in this new philosophy of science, because the citation indicated a relation with science as a practice (that is, Popper's 'context of discovery'). Only in a context like that of science studies as an interdisciplinary area (e.g., *Spiegel-Rösing* and *Price* 1977[83]) can citation analysis be a legitimate subject of study.

Citation *analysis*, thus, reflects another turn of the tables. After World War II, science had grown so expensive and so differentiated in disciplinary organization that new instruments were needed for its managerial control. From within the scientific institute, information retrieval posed a new challenge. At the level of society, Bush's *The Endless Frontier* (1945) should be mentioned here.[8] In this *Report to the President*, *Bush* requested political support for fundamental research, that is, as a separate domain of social organization and state intervention. Indeed, the late 1940s and the 1950s witness what can with hindsight be called 'the institutional phase of science policy' (e.g., *Spiegel-Rösing* 1973[81]). Since the 1950s, funding acknowledgements and institutional addresses regularly appear in scientific publications (*Gillmore* 1986,[33] p.

115; cf. *Rip* and *Hennekam* 1985[73]). In this context of science management and scientific information, citations can be used as proxies (*Adair* 1955;[2] *Garfield* 1955[24]).

Citation indexing inadvertently changes the system of reference for citation analysis. While citations can be used to trace intellectual influence and to retrieve information by taking the cited text as a lead to follow the history of a knowledge claim (*Latour* 1987[42]), the construction of an index inverts the time axis (*Wouters* 1997[92]). In citation analysis, citations are counted from the citing texts, and thus cited texts are provided with authority *by hindsight* (*Garfield* 1979[26]). This reflection changes the model from a historical to an evolutionary one: older texts constitute variations which compete for citations in 'current contents.' The analytical focus of citation analysis is on selection in the present: the operation is foregrounded. Therefore, stabilization and codification have now to be explained. Note the contrast with citation of the Bible for scholastic reasons.

Whereas citation is an emerging (reflexive) practice, citation analysis implies a reflexive theory. While this theory has not (yet) been articulated, the field may seem to be driven by measurement problems. However, the operation is entirely theoretical: citation analysis reconstructs scientific development in an evolutionary mode with reference to scientific developments which are themselves being continuously reconstructed. All the empirical sciences reflexively rewrite their histories in the light of new evidence. The implied evolutionary understanding of science is reinforced by citation analysis.

This implication is also part of the reflexive rewriting of the history of scientometrics as a field of science. What have citations meant for our specialty? While citations are used by historians to track developments of the sciences, citation analysts reconstruct history from a perspective in the present. A theory of citation becomes urgent when this perspective is understood as a cultural construct itself (*Mulkay* et al. 1983[66]). Because it is possible to change perspectives, a scientific text no longer has an inherent and *a priori* value. Each knowledge claim can be provided with a revised function during the further evolution of the distributions. Different functions can be equally valid or valid at different moments in time. A distribution of functions can be distinguished, and so the functions become uncertain and reflexive expectations.

The same authors can be cited because of different knowledge claims. The unit of analysis for citation *analysis* is the scientific paper, unless specified otherwise (e.g., *White* and *Griffith* 1981[89]). From an evolutionary perspective, the author can be considered as the retention mechanism of the credit that is attributed to a text by a citation. When credit has accumulated (*Latour* and *Woolgar* 1979[43]), the result may be incorporation into codified knowledge by obliteration (*Cozzens* 1985[17]), or even by

'eponymy' – that is, attaching a name to a phenomenon like the 'Zeeman-effect' (*Merton* 1957[61]). The retention mechanism feeds back on the citation cycles as one of its reflexive subdynamics.

In a social system, the retention mechanism for social accomplishments is usually the institution. However, the institution can be considered as yet another distribution of actors. By taking this uncertainty as unit of analysis, emerging discourse of science & technology policies has been able to intrude into the circle of reflections on scientific discourses (*Woolgar* 1991[91]). In citation analysis, this potential opening has been recognized by paying increasing attention to institutional addresses. Much effort in the 1980s, indeed, has gone into 'cleaning up' the Corporate Index of the *Science Citation Index* because, from a science policy perspective, individuals are less interesting units than institutions. Nowadays, the CD-ROM version of the *Science Citation Index* enables the analyst to search the institutional addresses for precise postal codes.

Citation analysis allows for choosing institutional frameworks as another perspective for aggregation (e.g., *Martin* and *Irvine* 1983;[58] *Moed* et al. 1985[64]). In other words, the unit of analysis can be varied. Different rules of aggregation, however, refer to different dynamics, and therefore the specification of different theoretical reflections is expected. Note that one has a dual problem in citation analysis: the unit of analysis can be either text or author, and the level of aggregation may vary. Elsewhere[51] we defined the dimensions of citation analysis at the *micro*-level by using the cross-tabling in Table 1.

The specifications at the micro-level refer to (aggregated) systems that generate specific hierarchies and dynamics by operating in a distributed mode, that is, in terms of micro-events. The various (sub-)systems participate in each citation to a greater or lesser extent by interacting. Rewards, for example, tend to help stratify the system into social hierarchies, journals help to structure the communication, while cognitive resources are aggregated in terms of more abstract categories like theories. Each event is a micro-operation, but the distributions of these interactions can be organized along different axes. This can be reflected using corresponding theories.

Table 1
Possible functions of citation relations at the disaggregated (micro) level

	Citing Author	Citing Text
Cited Author	Professional Relation	Reward
Cited Text	Cognitive Resource	Discursive Relation

Analogously, I propose the cross-table in Table 2 for the aggregated level of citations:

Table 2
Possible functions of citation relations at the aggregate level

	Citing Groups	Citing Document Sets
Cited Groups	social networks	hierarchies
Cited Document Sets	concept symbols	codification

The relation between the micro- and macro-level of analysis introduces the dynamics of reproduction into each dimension as yet another research question. One expects networks to be reproduced in a distributed mode but at specific locations (*Maturana* and *Varela* 1980;[59] *Rumelhardt* et al. 1986[74]). In this manner, a network with a structure is generated. This dynamic problem has been discussed by sociologists in terms of action/structure contingency relations (*Giddens* 1984;[29] *Luhmann* 1990;[54] cf. *Leydesdorff* 1993[47]). While theories about these complex relations tend to be formulated in terms of geometries (that is, in terms of multi-dimensional spaces and mappings), the dynamic analysis requires an algorithmic approach (*Gilbert* 1997[31]).

In summary: the mechanisms of aggregation can be specified in each dimension of citation analysis with reference to potentially different dynamics. While a dogma of micro-foundation on action has prevailed in economic and sociological analysis, aggregation in science is expected to contain both 'within group' and 'in-between group' variations (*Leydesdorff* 1995[48]). Thus, a complex dynamics is potentially generated along each axis. Action (that is, citation) is therefore a complex phenomenon. Furthermore, what is being aggregated can vary among research traditions. Accordingly, the interactive and the aggregative components of the phenomenological variations will be appreciated differently.

3. The reception of citation analysis in Science and Technology Studies

While citations were most fruitful for practicing scientists – allowing them to link social and textual information – the irreflexive usage of this measurement unit in citation analysis has generated resistance among active scientists. Citation analysis calls for a theory of what is being analyzed; citation analysts consequently tend to be in need of theoretical legitimation (*Luukkonen* 1997[56]). Can such a theory of citation be provided by Science and Technology Studies? What have citations and citation analysis meant for the empirical study of the sciences during the relatively short history of STS?

As early as 1978, Yehuda *Elkana*, Joshua *Lederberg*, Robert K. *Merton*, Arnold *Thackray*, and Harriet *Zuckerman* co-authored a first systematic reflection in what they called *Towards a Metric of Science: The Advent of Science Indicators*,[22] while earlier contributions had been programmatic to the enterprise of developing 'scientometrics' as a field of study (e.g., *Price* 1965a[70] and 1965b[71]). The 1970s witnessed the gradual emergence of the industrial practice of citation analysis (*Narin* 1976;[68] *Garfield* 1979[26]). Furthermore, Tibor *Braun* founded the journal *Scientometrics* in 1978 (cf. *Wouters* and *Leydesdorff* 1995[94]), and soon thereafter the first academic units for citation analysis were established (ISSRU, Budapest, 1983; CWTS, Leiden, 1984).

In terms of disciplinary affiliations, the response to the advent of citation analysis has been more enthusiastic among philosophers and historians of science (e.g., *White* et al., 1979[88]) than among sociologists (e.g., *Edge* 1979[21]). The 'new sociology of scientific knowledge' wished to focus on practices (e.g., *Gilbert* 1977;[30] *Gilbert* and *Mulkay* 1984[32]), and most of these scholars tended to avoid formalized measurement (*Chubin* and *Restivo* 1983[14]). During the 1980s, the systematic application of scientometric indicators to policy issues, however, triggered a practice of improving on the measurements (*Martin* and *Irvine* 1983;[58] *Moed* et al. 1985[64]). As noted, other indicators like co-words were developed (*Callon* et al. 1982;[9] cf. *Van Raan* 1988[85]), and citation analysis was increasingly used in empirical STS research (e.g., *Nadel* 1983;[67] *Cozzens* 1985[17]).

In 1987, I organized a workshop, followed by a theme issue of *Scientometrics* in 1989, in an attempt to bridge the gap between qualitative research in STS and scientometric methods (*Leydesdorff* et al. 1989[50]). It remained a brief encounter: ever since, the subfields of STS have increasingly specialized, as can be seen by using aggregated journal-journal citation analysis reflexively (*Leydesdorff* and *Van den Besselaar* 1997[53]). On the qualitative side, scientometrics tends to be type-cast as a rhetorical practice (e.g., *Woolgar* 1991;[91] cf. *Gilbert* 1977[30]). On the quantitative side, theoretical research has developed with reference to scientometric practices (e.g., *MacRoberts* and *MacRoberts* 1987;[57] *Luukkonen* 1990;[55] *Callon* et al. 1993;[11] *Leydesdorff* 1995[48]).

Nowadays, three main traditions can be distinguished in STS: (a) socio-historical analysis mainly using historical case study research for specifications, (b) quantitative studies oriented towards formalization and generalization, and (c) policy and management studies that utilize results from (a) and (b) pragmatically.[53] Citation analysis is relevant in these three traditions, but for very different reasons (*Cozzens* 1989;[18] *Luukkonen* 1990[55]).

4. Evolutionary cycles

Citation analysis has been of particular interest to science studies as an interdisciplinary field because it has allowed analysts to move back and forth between the cognitive, the textual, and the social dimensions of science in terms of socio-cognitive interactions. For example, the number of times an article was cited could be taken as an indicator of the impact of the cited author(s), and thus a *translation* could be made from the cognitive use of citations in a text to the social system of rewards operating in the scientific community. In the science policy arena, furthermore, the citation argument has helped to make scientists more aware of the social and communicative contexts of their arguments, and thus to legitimate the sociological analysis of the sciences.

Both within STS and in neighbouring disciplines, this placing of the sciences into contexts without further theoretical and methodological reflection has been criticized. One is not allowed to infer from the impact of an article, measurable in terms of numbers of citations, the quality or lack of quality of a particular researcher or research group (*Collins* 1985[15]). The use of archival records to measure social structural properties has been criticized from the side of social network analysis (e.g., *Burt* 1983[7]). *Mulkay* et al. (1983)[66] have noted the methodological bias in inferring the other way around from citations to cognitive impact. Discursive, social, and cognitive functions are neither symmetrical nor synchronous. Furthermore, citation analysis can be abused for political purposes if not sufficiently based in reflected norms of 'best practice' (cf. *Glänzel* 1996[34]).

STS has split into various research traditions which tend to be highly critical of each other's assumptions and 'best practices'. Yet citation, with its specifiable relevance in all these dimensions, remains an attractive candidate for studying the differences. Is one able to specify a hierarchy among the potentially different functions of citations? Of course, a hierarchy can be constructed from each of the competing perspectives. But do criteria exist in this post-modern world to justify the choice of one selection over another?

In this study, I have focused on the generation of citations as carriers of cognitive information. For this purpose, the cognitive dimension was considered as an overlay that was first achieved historically and then codified on the basis of interactions among scientists and their communications. It is both social and cognitive, both a network of actors and a network of networks. Yet it is highly selective, since the networks operate in terms of selections. Scientific cognitions can be analyzed as the unintended (that is, latent) eigenvalues and eigenfrequencies of the networks of these complex interactions.

Cognitions thus conceptualized remain uncertain, subject to discussion, and in continuous flux.

Among other things, the operation of two layers upon each other in a distributed mode enables this system to develop 'operational closure' as in the case of paradigm formation (cf. *Luhmann* 1990;[53] *Leydesdorff* 1995[48]). During the generational phase, the cognitive dimension can be considered as a dependent variable. In evolutionary developments, however, the emerging dimension is able to take over control by selecting increasingly upon the underlying ones. In the mature phase, the different dimensions select upon each other, and the locus of control may shift unexpectedly in terms of the densities of the selections. These alterations in frequencies induce life-cycles: what had to be referenced at one moment is taken for granted at the next moment, or perhaps codified as in the case of eponymy. In a complex dynamics, selection and variation are sub-dynamics that can only be identified by taking a theoretical position or, in other words, by specifying a window of observation.

Each window of observation allows for another assessment of the data under study. Once this has been accepted among the analysts, it becomes important to specify which window one takes, so that the partial insights thus obtained can be made reflexively clear in terms of their relevance. In this post-modern regime, the quest for a single theory of citation has to give way to the debate among citation analysts who have become aware of the relativity of their positions. By being reflexive about their positions, these authors may be able to contribute to each others' self-understanding and thereby reinforce quality control among themselves. Whether the resulting interactions can be codified in a meta-theory remains uncertain.

5. Summary and conclusions

I have argued that the quest for a grand theory of citation implies a meta-theoretical question, since citation analysis is itself based on a theoretical reflection of scientific practices that have been shaped historically. The historical, philosophical, and/or sociological positions taken by citation analysts, however, have usually remained implicit. Although theoretical notions from these disciplines have guided the research program of scientometrics as heuristics, the analytical unravelling of citation as a complex unity into different meanings might endanger the legitimation of citation analysis practices (*Luukkonen* 1997[56]). Theoretical discussions could easily have torn the field of scientometrics apart – as has happened with STS in general[53] – despite this specialty's firm unity based on its technological interest in exploring the potentials of the relevant databases (*Wouters* and *Leydesdorff* 1994[94]).

Our recent understanding of social processes as the selective operation of distributions upon underlying distributions provides us with ground for elaborating scientometrics in an algorithmic mode. The various mapping techniques can then be appreciated as providing geometrical representations. Contributions from the qualitative side are selected as far as they allow us to specify equations and routines that can be made relevant to the understanding of the sciences in terms of the massive data that are becoming increasingly available.

This 'translation' of qualitative insights into formalisms is well-known, for example, in econometrics. As *Langton* (1989)[41] expressed it: theories specify 'genotypes', while the model simulates the 'phenotype' because one is able to identify the interaction terms. Such an approach, however, requires a thorough reflection on the literature: when are qualitative scholars analyzing 'variation and selection' at each moment in time, and when is the discussion focussed on 'change and stabilization' over time? These are different sub-dynamics of the complex system, since only some (instantaneous) selections can be selected for stabilization (over time).

How analytically distinct are the models, and how are they confused by taking, for example, too many contextual factors on board? When have qualitative insights been generalized? Secondly, have attempts been made to test using independent datasets? Citations seem an appropriate subject for discussing these issues in both qualitative and quantitative terms: the *Science Citation Index*, for example, has provided a testing ground for theories in many different directions. Other databases are increasingly available on CD-ROM and the Internet. However, the process of theoretical articulation must be highly reflexive if the scientometrician wishes to understand and profit from the qualitative side of STS.

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