Forces and functions in scientific communication:

an analysis of their interplay

Hans E. Roosendaal [1] and Peter A. Th. M. Geurts [2]

Dans la vie, il n'y a pas de solutions.*
Il y a des forces en marche: il faut les créer et les solutions suivent.
(Vol de nuit, Antoine de Saint-Exupéry, Ch. 19)

"Forces and functions in scientific communication: an analysis of their interplay" by Hans E. Roosendaal and Peter A. Th.M. Geurts. Date: 1 April 1999.
1) Educational and Scientific Information Centre (ESIC) Twente University, The Netherlands
2) Faculty of Public Administration, Twente University, The Netherlands
*) In life there are no solutions. There are forces in motion: They need to be created and solutions follow.

Abstract:

This article deals with the transformation of the familiar, linear scientific information chain into an interactive scientific communication “network” in response to concomitant changes in scientific research and education. Societal conditions are seen to lead worldwide to the concept of strategic research: research dominated by "economy of scope". Strategic research leads to transnational research enterprises - universities and other research institutions - with a focus on return of research capital investment, and thus on intellectual capital. This development calls for new ways of knowledge management that in turn has consequences for scientific communication.

The scientific communication market is described in terms of four main forces and their interplay. These forces are the actors (the author/reader pair), accessibility, content, and applicability. Scientific communication is described in terms of its four functions: registration, awareness, certification and archive.

These forces and functions allow a structural analysis of the scientific communication market and allow to discuss aspects of structural continuity in e.g. describing the transformation from a paper-based system to communication in an electronic environment. The developments in research are seen to emphasise the already existing autonomous development of a "unified archive". Also these developments lead us to review certification policies to include elements external to research and to consider new structures for communication, and publications. The new structures are a result of the interactions in the market as described by the forces and the functions. The distinction between formal and informal communication is seen to become less useful. The need to review the structure and organisation of the market becomes evident, in particular if we consider communication during research as well. This leads us to speculate if elements of the virtual organisation are of relevance. Finally, the need for a coherent research programme on scientific communication is discussed.

Introduction

At present we are experiencing a transformation in the familiar scientific information chain, i.e. from author to publisher to library to reader.
In this article we will analyse this transformation. We take the view that this transformation is of a structural nature rather than primarily driven by technology forces: the linear information chain is being fundamentally transformed into an interactive communication “network”. Such a “network” is required to support the present, societal demands for knowledge growth and management.

A starting point is that our current policies and practices in science and communication are “not ideal for an optimal exchange and refinement of our knowledge” (1) while this is more than needed in our present, knowledge intensive society. To this end we need to study the role of publications in science. These publications are at present the main carriers for a “heterogeneous exchange of knowledge which is seminal to the progress of science.” (1)
However, we should not stop at this point. If we acknowledge that the above points are of relevance, we should also look at possible configurations for scientific communication (2), as communication can only be effective and efficient, if its configuration appeals to the research community, also in its relation to society at large. Also differences in configurations between disciplines need to be studied, as these differences should not impede knowledge transfer in transdisciplinary or interdisciplinary research. We need thus to address the role of communication and its organisation in relation to the entire research process.
This leads us to the issue of complexity and above all the seeming abundance of scientific information. It has often been stated and is still stated that the nowadays excessive rate of production of original scientific work cannot but in the end retard scientific progress, as there is no time anymore for the proper ageing of theories (3). And indeed we seem to suffer from abundance, rather than from a scarcity of information and data.

The cure to the above mentioned symptoms is not to slow down scientific research and education. Rather we need new methods of scientific communication that allow to greatly speeding up the advancement of science. Research time to explore the abundance of information and data seems the main issue. This is the focus for improving the effectiveness and efficiency of the scientific communication system.
These arguments support the vision of a structural - or “strategic” - transformation to a scientific communication “network” as opposed to a more mechanical -or “tactical” - transformation of the information chain. The latter can only result in just an improvement of the existing system.

Technology serves as an important driving force as it enables further developments in the research process. Above all, technology empowers

researchers to induce a structural change in their communication configuration. If this change can lead to improve the advancement of knowledge, this opportunity will be seized.
In consequence, changes in technology may well lead to structural changes in the way the science process is perceived as its communication reflects to a high degree most relevant aspects of this science process. E.g. the arrangement of the experimental article re-enacts the process of induction. A modular approach to a scientific article as is presently being investigated (4) may well lead to consequences in the research process.

We will analyse the thesis that the transformation is of a structural nature. We will analyse aspects of the process of scientific communication in its relation to scientific information, and its relation to the science process, its goals and its stakeholders and how this process relates to actual societal demands.
This approach necessitates an analysis of the main constituents of scientific communication and its dynamics. Therefore, we will define a set of main functions to be performed in scientific communication rather than analysing needs related to scientific information.
The functions are defined as intrinsically invariant – or otherwise stated are independent of changes in parameters such as information technology. Because these functions are invariant, we are able to study the structure of the scientific communication process independent of technological conditions. The parameters of the functions will, however, depend on technological conditions.
This property in our approach is relevant as some discussions on the transformation of the information chain refer to an information crisis (5) and a conflict between the stakeholders in the information chain.
An analysis in terms of functions allows investigating and discussing aspects of continuity. This analysis addresses the balance between the functions rather than focusing on isolated aspects such as "overproduction" of information.
This methodological approach is most relevant if the transformation to a communication “network” is a structural one.

In the next section we will discuss the societal conditions driving this transformation; section 3 will discuss the consequences for scientific communication; section 4 will analyse in detail the main forces and functions of scientific communication, and section 5 will finally describe the strategic consequences for the stakeholders, such as a future structure and organisation within the overall science and related communication process.

2. Societal Trends

2.1 General

Over the last decades we have noted a trend in society to become more demanding with respect to science (see e.g.: 6-9). The ending of the Cold War, which with regards to science led to a severe reduction of research programmes, has accelerated this trend. This is in particular correct for those research programmes related to the arms industry. Paradoxically these research programmes were based on research philosophies that came very close to the notion that academic research will eventually lead to spin-offs relevant to society at large. And indeed, research did deliver as can be witnessed by the extremely fast development of e.g. semiconductor research leading to the rapid deployment of computer technology or, as another example, the development of nuclear research oriented instrumentation contributing to the development of our present day medical instrumentation, e.g. in cancer theory and scanning techniques.
However, there are also examples where the "return on scientific capital" is less satisfactory, such as e.g. the nuclear fusion reactor or space research. Despite a somewhat slow start, solar energy technology now comes to fruition and lives up to its promises.
These examples are taken from the exact sciences. The general observation is equally valid for the social and behavioural sciences.

Nevertheless, society – and industry - are continuously upgrading their demands on "return of scientific capital". The main parameter is the turnaround time of scientific research. The orientation on the market - i.e. the demand for direct applicability of research results-has become stronger and the more limited funds for research- both public and industrial funds- have lead to a stronger focus on the scientific scope of research to be funded.
Over the last decades we are witnessing a change in research from a general research philosophy that can be described by "economy of scale" to an "economy of scope". "Economy of scale" is characterised by "unlimited" research resources, allowing that individual research was primarily driven by scientific curiosity. "Economy of scope" is characterised by scarcity in research resources. This scarcity leads to selectivity along societal priorities, and demands research breakthroughs within an acceptable time horizon.

As a corollary to this "economy of scope" in research, we witness tighter planning of research at large and the development of "strategic research". Strategic research means the active planning of entire research programmes and represents a trend towards an "a priori" mode or "conceptual" attitude towards research discoveries (10). This as opposed to a more "tactical" or "a posteriori" attitude practised after the Second World War till the eighties.

The development of strategic research is further pushed by the fact that intellectual capital is considered to be the “main engine for (industrial) development rather than monetary capital, natural resources, or (very) traditionally land” (11).

Thus "scientific capital" consisting of intellectual capital and a proper organisation of this intellectual capital leads to strategic research, which in turn leads to more "a priori" planning of research programmes. This planning includes the societal implementation of research results.

The above sketched development seems somewhat paradoxical as it is generally held that the Cold War was won by the Western world because of its rapid technological development that could not be met by the communist world. However, the West had a more tactical attitude looking at applied research as a spin-off of wider academic research programmes, whereas the East had already for long introduced strict planning, albeit ideological planning, of research.

In conclusion, strategic research has to fulfil societal demands in combination with research initiatives driven by curiosity. Strategic research and its consequences are discussed below.

2.2. "Strategic Research"

The trend to strategic research can be witnessed in the research policies of the industry worldwide. Many industrial companies have been or are reorganising their research policies towards more economy of scope, sometimes even resulting in a (partial) divestment of their research laboratories.

Also national governments worldwide and supranational bodies have started, continued and strengthened a fundamental reorganisation of their higher education programmes and are influencing the research programmes by their funding strategies.

In order to further "strategic research", governments attempt to establish "centres of excellence" within a specific research programme. In this way institutionalised accountability for entire research programmes is introduced on top of the accountability of the individual researcher. His research efforts are usually reported in the researcher's individual publications. Additionally, programme evaluations are generally introduced by national and supranational governments.

Academic research has always been international, at least in a large number of more fundamental research disciplines such as mathematics, physics, chemistry, materials science etc.. The above developments at universities and other research institutes add a new component to the trend towards institutionalised

international, transnational or global research entities. One of the consequences of strategic research is that universities and research institutions are developing into transnational research corporations with a strong market orientation. As a consequence they have a long term focus on research combined with a shorter focus on management. Pharmaceutical research is a good example of research with a strong societal component and a strong link to industry.
Strategic research means stronger planning of entire research programmes in an "a priori" mode with a shorter research-planning horizon. In the end, it will lead to transnational integrated research enterprises (such as e.g. CERN). This will lead to reduce the control of national governments on these institutions.

We have discussed the consequences of the organisation of research. It goes without saying that the above mentioned developments also have consequences for the educational tasks of the universities and other institutes of higher education. Curricula need to be trimmed towards this new research philosophy. They are generally shortened and at the same time more focused. People will be less educated in the "academic" way, but more trained to apply their knowledge directly on the short term. As a result, the demand for re-education, or continuous education, becomes stronger (see also 8, 9). This development will add to the revenue stream of these institutes for higher education.

These developments will result in managerial changes for universities and research institutes. Universities develop into transnational or global networks of centres of excellence in a highly competitive world. In short, the core competencies of these centres of excellence are the usual competencies such as problem finding and solving, verification and falsification, and new competencies like the "economic" elements (12) opportunities possibly leading to innovation, scarcity, preference, cost, choice and competition. Cost stands for the usual cost factors such as money, time, foregone benefits, and psychological and political costs. These core competencies are the main instruments needed to manage the university enterprise. This represents a shift away from a primarily "curiosity driven" university. In essence we witness a shift in the balance between supply and demand: societal demands translate into conditions for research.

The main scarcity seems intellectual or scientific capital, which is equivalent to internal research time. Knowledge is thus the main engine for the institution's revenue stream. This knowledge must be properly managed and matched to societal and industrial demands. We now see the development of a new discipline of knowledge management. Its main beneficiaries will be the universities and other research institutions in need to explore their scientific capital.

It has often been stated (13) that it is much more difficult to see a problem than to find a solution for it. And indeed, it is nowadays an even more tedious task of research management to see the right problems that are to be addressed in the new competitive environment of strategic research.

2.3 Some methodological aspects of "strategic research"

Following Lakatos (14, 15) the problems chosen in powerful research programmes are determined by the heuristics of the programme, i.e. the research questions and methodology. A programme has positive heuristics when it produces research questions of a higher order than its original research questions.

Lakatos concludes that his methodology of scientific research programmes accounts largely for the relative autonomy of "theoretical science". And undoubtedly, such autonomy has lead to the positive development of the scientific enterprise, as we know it at present.
These definitions of positive heuristics are based on a definition internal to research. However, the development of our universities into transnational centres of excellence requires not only internal heuristics for the research programmes but demand also some sort of external heuristics. These external heuristics are based on the applicability of the research results for societal purposes.

A task for strategic research is to translate such external heuristics into internal heuristics that can provide a solid basis for the research accountability of both the institution and the individual researcher. Care must be taken to avoid a conflict between external and internal heuristics. Such a conflict would easily turn a research programme into a degenerating phase.

It has been observed (1) that "knowledge growth has been most robust and resilient when scientific communication and the freedom they entail are openly respected and encouraged" Scientific knowledge seems "to evolve in a spontaneous order and achieves progress by abandoning problem solutions that are less good than the competition" (12). However, in strategic research there may be other, more economic reasons rather than methodological to settle a competitive dispute of research in relation to society.

This shows that there are cultural aspects inherent to strategic research. We have observed that the knowledge industry at large (universities, research institutions, industry, etc.) requires, because of its new entrepreneurial orientation a novel approach to knowledge management characterised by "economy of scope".

An important issue is to identify and to develop a new "normative culture" of strategic research. This seems a key issue for the future development of scientific communication. Our present system of research publications as a formal part of scientific communication is based on the existence of a well-defined normative culture (16).

Thus within the broader realm of scientific communication the question “are research publications in a degenerating phase of the communication programme,

and do we need broader vehicles of scientific communication?" is a very legitimate one.

In order to address this question we will use a methodology based on analysing scientific communication in its main forces and functions and their development under changing environmental conditions.

2.4 Concluding remarks

Societal demands have led to the development of "strategic research" in response to the need to develop an "economy of scope" within research. Universities and other research institutions develop into transnational strategic research enterprises, into "centres of excellence". Intellectual capital is the main engine of progress of this knowledge industry. Knowledge management is developing into a strategic research discipline in its own right.
Strategic research requires its own methodology and this has been seen to have far reaching consequences for the communication needed to support this strategic research. One aspect is the proper evaluation of research within this new context. The question is if the present instrumentation of scientific communication is adequate.

3. Consequences for scientific communication and choice for a methodology

Scientific communication serves the progress of (strategic) research. The overall objective of scientific communication is growth of knowledge by improving the effectiveness and efficiency of research. A task is to reconciliate such seemingly opposing conditions as careful planning of research programmes and spontaneous evolution of research. As discussed, a possible solution lies in matching external and internal heuristics.

Scientific communication is also relevant to proper knowledge management: how can it support strategic research in evaluating its results, and the institutions and individuals who generate these results? How can we define the competitive environment? It should provide a proper "measure" taking into account the development under the present conditions of steady state science (17, 18) and finding a proper balance between programmes of basic and applied nature.
The issue seems not only to solve the research problems at hand but also to find the research problem of relevance. The effectivity and efficiency of scientific communication is determined by its combined ability in facilitating both the generation of relevant research problems (or raising the right questions) and the solution of these problems (or giving the right answers). This also relates to the issue of use, availability and retrievability of information.
Just to mention an example: information (or data for that matter) is not anymore an element of scarcity. Rather research time (and money) to explore the abundance of information is the main element of scarcity.
The added value is not anymore in information proper but in its effective and efficient communication, or knowledge management.
In combination to the development of strategic research this makes scientific communication a strategic issue, both at the level of the research institution and of the individual researcher.
It is therefore subject to the same economic “scarcity” elements as mentioned before.
Just as societal conditions have been seen to translate into research conditions, strategic research conditions translate into conditions for scientific communication.

Thus strategic research will represent a new balance between the three classical questions that we seek answers for (19): 1. what range of problems is worth investigating, 2. how is this range to be investigated, and 3. what do the results of these investigations mean?
The strategic research developments impact on all answers to these questions.
We realise that this is not new. It is well known that in the seventeenth century Huygens devoted a major part of his scientific life to investigating vibrations and pendula (20). While this led to a series of very fundamental observations,

Huygens' research programme was evidently driven by the need for highly reliable ship clocks in all naval countries, and in particular in The Netherlands.

A criticism on present day research is that it leads to a redundancy in research efforts. Certainly one of the objectives of strategic research is to reduce redundancy by better planning of (transnational) research programmes. (On the other hand, as Merton (16) has already shown, we should not see multiple or repeated discoveries as an inefficiency of the research system but rather as an indicator for the maturity of such a discovery.)

We need to make a clear distinction between genuine multiple discoveries and inefficient research and communication. One of the main criteria for an effective and efficient scientific communication system is that it reduces redundancy and increases the rate of detection of genuine multiples. This is even more important in a strategic research environment. At the same token, redundancy should not be confused with obsolescence. Especially in higher codified scientific disciplines, such as e.g. High Energy Physics, the rate of obsolescence of research results, and thus publications is rather high. This reflects the rapid progress in these disciplines, for which obsolescence is a natural, rational characteristic (16).

The question arises if this can be achieved within the present scheme of distinction between "formal" and "informal" communication. We envisage a trend towards more formalising of "informal" communication. This trend adds to the protection of the intellectual property of the individual researcher within a research institution.

In the next section we will use a structural approach to the concept of scientific communication by analysing the scientific communication market with its four main functions that we have already briefly introduced.

In taking this approach we acknowledge that we are in need of a clear methodology to analyse a structural change. This structural change is important to scientific publishing as under the influence of “strategic research” the notion of "must have" information might well be shifting.
By using a set of communication functions that by definition are each invariant to structural changes, we may assume that a future system will in this respect not be incommensurable with the present system. However, structural changes will have an impact on the balance between these functions.

In summary, by describing and analysing the change in functional balance of scientific communication it is implied that this change will be intelligible and commensurable. This also implies that the developments can provide opportunities for the presently existing "information industry".

4. Analysis of scientific communication

4.1 The market

In the most general sense we can state that scientific communication takes place between researchers, mostly acting in some sort of capacity as authors and readers. Their objective is to exchange (units of) information. The market place of scientific communication consists of authors and readers as generic actors or stakeholders. Authors are not only stakeholders of this marketplace by authoring a unit of information, e.g. such as a scientific article or by providing a set of data. They are also heavy users of this market place, as they want their product to be made available for all readers. Furthermore, their product is their main expression of accountability within the research enterprise. They claim in this way their priority of discovery. This is a long-standing practice. Already "since the end of the seventeenth century this priority of discovery is the norm and prior journal publication its criterion" (4b, 19).

It has been stated (4a, 21, 22) that authors want to publish **more** and have their product widely available, while readers want to read **less**, but want to be informed of all that is relevant for their research at hand. They want this information available just in time. They want to be guaranteed that they can and will be informed of all that is relevant to them.

From these arguments we deduce that a unit of information, be it a journal article, dataset or otherwise, is not a functional unit of communication, but requires the interaction with either the author or the reader or both to become a functional unit or a set of functional units.
Thus scientific communication is defined as the ensemble of functional units, whereas scientific information is the ensemble of units of information.
Within this definition it is inconsistent to assume that a unit of information can separate an author's market from a reader's market. It rather shows that such a separation cannot exist. This means that we reject a linear view of the market, and this is consistent with the well-known fact that the scientific communication market is a market with a strong, direct feedback system.

Thus the scientific communication market, or short the market, consists of authors and readers (actor pair) as generic stakeholders. They require (sections 2 and 3) availability and retrievability (accessibility pair) of all sorts of units of information. Their objective is to generate questions and to provide answers (content pair) in order to apply them in science or technology (applicability pair). We make a distinction between science and technology. We will use the word science when the application is part of the scientific feedback loop and technology when the application is brought outside this loop into another regime.

Each pair is seen to have a more deterministic and a more indeterministic component resulting in dynamic, sometimes internally opposing interactions. E.g. an answer is more deterministic than a question.
Most generally, the forces can be grouped in a tetraeder with in each vertex a force. This tetraeder represents the following equation:

F(*scientific communication market*)=***F***(*actor, content, accessibility, applicability*)

There are four triangular planes with one force in each of its vertices. By observing that only those planes are relevant that contain both the actor and content forces, this tetraeder then collapses into the two-dimensional diagram of Figure 1.

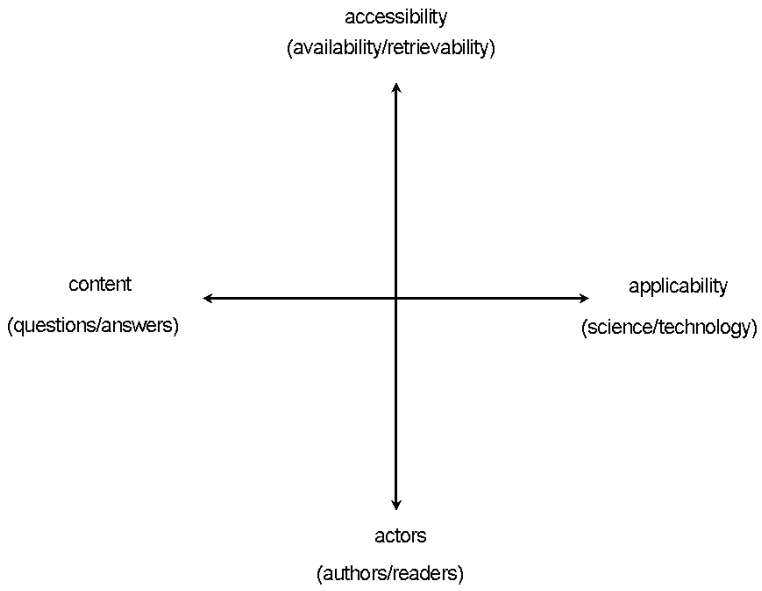

Figure 1:The four forces in the scientific communication market

The vertical axis is seen to describe primarily the market dynamics and modes of transaction whereas the horizontal axis describes different aspects of the content being negotiated in this market. The market is defined as the place of balance of these forces, as an "agora" of scientific conduct and discourse.

If we accept this description of the market, an immediate conclusion is that there is no such thing as an information market, but instead there is an ensemble of units of information creating an "information space". In this view, libraries and publishers belong to this information or product space that is a subset of the generic scientific communication market. From this description it becomes

obvious that the present developments in information technology, and especially the Internet, do represent an important empowerment of the market's main stakeholders, the author and the reader.

4.2 Functions in scientific communication

As stated in the previous section we have argued for a functional analysis of the market. This approach is consistent with our environmental analysis of the developments of strategic research.
In analogy with our analysis of the market we will try to identify the main functions of scientific communication.

Following (23, 4, 22) we define as the familiar main functions of scientific communication the registration, awareness, certification and archive functions. In a similar way as with the market, we can visualise these four main functions as in Figure 2. (Like before with the four forces, we can group these four functions in a tetraeder. And again by observing that interaction planes are void when they do not contain the registration and the archive function, this tetraeder then collapses into Figure 2).

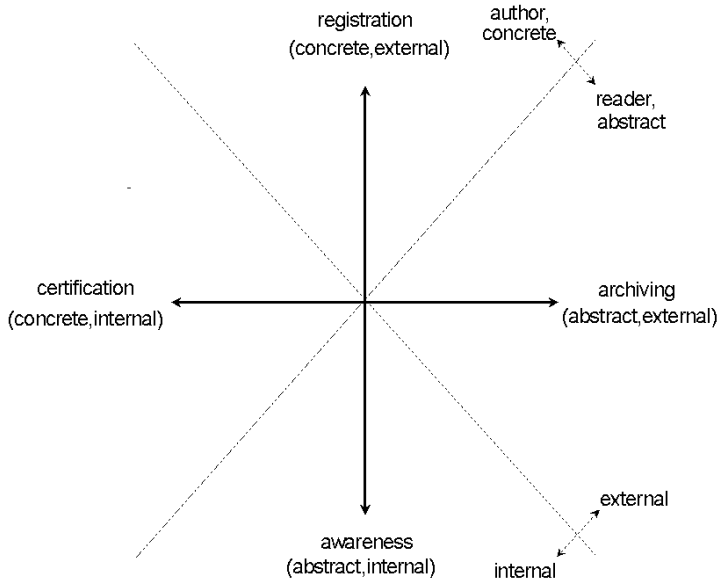

Figure 2:The four functions of scientific communication

Like in the discussion of the market we arrive at two axes: the vertical axis describes registration and awareness which can both be seen as different aspects of scientific observation, whereas the horizontal axis describes certification and

archiving which can be seen as different aspects of scientific judgement.
This interpretation shows some similarities with the familiar description of the four main functions of psychology by Jung (24). We mention this analogy only as it will prove useful for our classification of the communication functions. We will use such a classification for further conclusions on the development of these functions, and the market place.

We arrive at the following classification: the registration function is both a concrete and objective function, the awareness function is abstract and subjective, the certification function is concrete and subjective, and finally the archive function is an abstract and objective function. There is a half plane of two objective functions, and a half plane of two subjective functions. Similarly, there is a concrete half plane and an abstract half plane. Following the familiar classification of the communication functions into author and reader functions (23) we see that the author functions are the concrete functions and the reader functions are the abstract functions.

This classification is of relevance as a concrete, objective function is by definition an explicit and external function (registration), an abstract and objective function is implicit and external (archive), a concrete and subjective function is explicit and internal (certification), and an abstract and subjective function is implicit and internal (awareness).

Inspecting Figure 2 we see that the subjective communication functions are the functions that are *internal* to the research process, whereas the objective functions are *external* to the research process. By their nature registration and archiving can therefore be easily outsourced within the market to the product space, viz. the publisher and the library.
Whereas in this description we tend to focus on the functions, and for obvious reasons as it leads to important insight on what activities can be outsourced by the research community, we should realise that scientific communication results above all from the interactions or rather transactions between the functions.

These transactions include the transfer of content (primarily the author-reader interface) and the transfer of (consolidated) knowledge (primarily the subjective-objective interface). The latter is relevant for strategic research as it determines largely its degree of applicability. The trend in the market will be towards emphasising these transactions rather than the functions only.

Figure 2 shows the overall communication process as it is embedded within the research process. It also shows which parts of this process can be externalised out of the research process.

As an illustration of the four communication functions, let us briefly analyse the birth of the first research journals, Le Journal des Sçavans (Paris) and the

Philosophical Transactions by the Royal Society of London. One may assume that the main reason for the birth of these journals was the growth of scientific activity in the seventeenth century and the concomitant breakdown of the author driven communication system of that time of writing letters reporting their recent research results to author selected readers, and of writing compilations of their work in the form of a book. The result of this system was that relevant readers were not necessarily evenly informed: the scientific enterprise got out of phase, resulting in a loss of effectiveness and efficiency. Thus the birth of the journal was primarily awareness driven. This was assisted by technological developments that allowed the deployment of an efficient postal system in Western Europe at that time. Thus one might also see the birth of the journal as technology driven. However, technology seems more a necessary facilitator than a boundary condition. The Royal Society took charge of the registration and certification functions by organising the editorial office by appointing Mr Henry Oldenburg as the journal's editor and by having the submitted articles reviewed by members of the Council of the Society. The journal itself developed quickly as the archive per se.

Table 1: Citations from correspondence of Henri Oldenburg - Robert Boyle

O 1: The Society alwayes intended, and, I think, hath practised hitherto, what you recommend concerning ye registring of ye time, when any Observation or Expt is first mentioned.....

O 2: have declared it again, yt it should be punctually observed: in regard of wch Monsr. de Zulichem (Huygens) hath been written to, *to communicate freely to ye Society*, what new discoveries he maketh, or wt new Expts he tryeth, the Society being very carefull of registring as well the person and time of any new matter, imparted to ym, as the matter itselfe; *whereby the honor of ye invention will be inviolably preserved to all posterity*....

O 3: This justice and generosity of our Society is exceedingly commendable, and doth rejoyce me, as often as I think on't, chiefly upon this account, yt I thence persuade myselfe, yt all Ingenious men will be thereby incouraged to impart their knowledge and discoveryes, as farre as they may, not doubting of ye Observance of ye Old Law, of *Suum cuique tribuere*.

B 1: I mightly justly be thought too little sensible of my own Interest, if I should altogether decline so civil an Invitation, and neglect the opportunity of having some of my Memoirs preserv'd, by being incorporated into a Collection, that is like to be as *lasting* as *useful*.

Some of these aspects are nicely demonstrated by citations from a correspondence

between Oldenburg and Robert Boyle presented in Table 1, which is taken from Merton (16). Indeed, the citations illustrate the importance of registration for priority reasons and emphasise the point that **the** archive must be lasting and useful.

In conclusion, the use of the four functions provides a consistent analysis of formal and informal scientific communication. It may be questioned if these four functions, together with the transactions between them, provide a comprehensive description of scientific communication. This is a condition for the structural approach that we have taken, in particular if we want to apply the functions to arrive at conclusions, based on structural continuity, on strategic repositioning in the market (see next section 5).

External functions: registration and archiving

Within an electronic communication environment the present focus of development is on the two external functions. The function of registration is already fully matured with the exception of the intellectual property aspects of integrity of the communication and copyright issues.

For the archive function we have observed that both publishers and libraries are creating electronic archives or warehouses of information material under their control allowing distribution of this information through a variety of different media. First attempts are being made to connect these archives into a more distributed system. This forces to introduce conditions for transparency raising the issue of responsibility for such a distributed system and the issue of organisation of such a distributed archive. Do we need to standardise technology and to what extent? Will such an archive allow the author and reader to integrate the information into a personal archive? This is no doubt desired and should be one of the main objectives of such an archive. From Figure 2 we see that the archive function serves as a main transaction function or “sluice” between author and reader. This raises the issue of integrating informal communication into the platform of such an archive, which in turn leads to an integration of formal and informal communication. This means formalising informal communication into one and the same platform and management system. A result of these developments will be that the now distinct roles of publishers and libraries will be merged and will become nodes in the overall management of scientific communication.

Internal functions: certification and awareness

The certification function has been and is under continuous discussion. A wide variety of schemes is being proposed. It is particularly the certification function that might be subject to strong development under a strategic research regime. It has to be investigated how "economic" aspects related to the concept of "centres of excellence" will influence certification of research results. Gross (19) already describes peer review as a negotiation on the level of claims permissible in a

scientific article. The higher the level, the higher the article's status; the higher the status, the more difficult the negotiations. And indeed, under conditions of strategic research the negotiations might well become even more difficult, and the role of the referee needs further attention (12, 16). Merton (16) stresses in particular the strong relationship between intellectual property, and thus applicability, and the referee system. The referee system provides a clear authoritative system for the research enterprise and its rules of conduct will continue to be discussed within the wider context of the goals and applicability of research (see also 25). It makes a difference if a referee, when in doubt, is inclined to accept or reject an article. Intermediate schemes are also being proposed (26): Referees can add comments to an article that allows the author to make revisions or, if so desired, to withdraw from publication.
The transformation into a real communication “network” needs to address the issue of certification, and the question arises if certification can and will remain primarily restricted to research internal methodological arguments (internal heuristics) or that more and more external elements of a more economic nature will be added (external heuristics). In this context, economic means that it may be more rational, and thus sufficient, not to use the best in the methodological sense. Such a development could change the rules for the advancement of science, or has already changed these rules by creating "centres of excellence". And, as we have seen, we may be in need for a new normative structure specific for strategic research.

This will be reflected in the way science will be communicated. To illustrate this point, over the last decades we have witnessed a clear change in emphasis from the collection of information proper, such as data, towards the application of data which requires new schemes of clustering.
In terms of Popper (27) we are less concerned to answer the questions of the empiricist such as "how do you know" and "what is the source of this assertion” but focus instead on "what is the purpose" of strategic research and "what does it answer". This represents a clear shift towards more “mature” scientific communication at large.

The most difficult function, the awareness function - the real engine in the communication process- is also being tackled. Research on the modularity of scientific communication has been started (4). Research on science indicators is key to analysing this function (28). Science indicators also play an important role in the discussion on certification.

The discussion on intellectual property and its consequences for certification and registration signalises that a discussion on the normative culture in (strategic) research is needed.

Discussion and concluding remarks
An alternative to our approach is to analyse the needs of the stakeholders in the

market place. Such an analysis is reported in the literature (4a). Within our present methodology, the analysis of needs must be seen as a more tactical (or mechanical) approach to scientific communication. The analysis of needs can be generalised into a description by function (21, 22) in order to bring the discussion to the structural level. Three of six needs mentioned in (4a) we see as relevant for our discussion. These three needs are the need for more general scientific standards determining the social structures within the scientific enterprise; the need for a universal platform for communication; and the need for ownership protection for all stakeholders in the market. We have seen that the issue of intellectual property will probably become even more important than at present, both for the individual researcher and the research institution.
If we look at the (normative) structure of science according to Merton (16) the claims of universalism and communalism are most relevant to this discussion. From communalism it is often derived that knowledge is a common property and communication is a public process. At the same time, we have seen that communication is a value-added process and that the applicability and management of knowledge is of concern. From the discussion of the functions it may be clear that the functions not only deal with these needs but also set them in a wider perspective. The product space, as we discussed in section xxx, can then be defined at the operational level with the result that the product space is included in the external functions of scientific communication. This leads us to conclude that the set of functions does give a complete description of the configuration of scientific communication.

It is interesting to see that in reducing the tetraeders describing the forces and functions to the two-dimensional representations of Figures 1 and 2 (section 4.1), we used different criteria for the market forces than for the communication functions. With respect to the market forces we postulated that the actor and content forces are indispensable, as these forces are most generic and internal to the market as opposed to the external forces of accessibility and applicability. With respect to the functions we postulated that the external functions are indispensable.

These choices are consistent if we consider the dynamics and time aspects of the market and its functions. Although we have seen that the overall market process and the overall communication process cannot be linearised in time as these are feedback processes, one can linearise each individual process like one can linearise each individual research process (see e.g. 15). The individual market process is initiated by its internal forces whereas the individual communication process is initiated by its external functions. The overall market process can be seen as a superposition of individual processes, but not as a simple linear superposition, just as the communication for different phases of the research process cannot be described as a linear superposition of specific communication functions. An interesting consequence of this argument is that registration must precede certification, which indeed it does. In turn, certification can result in

lifting registration. Submission of an article starts certification and can be the final registration if the article is published as is. Revisions arising from certification may lead to registration (as accepted after revisions). Rejection leads to lifting the existing (pre)-registration.

4.3 Some consequences

The above description of the market and its functions has aimed to provide a consistent description of the main forces in the market required to generate knowledge in the widest (societal) sense, and how scientific communication provides dynamics to this market. Scientific information has been seen to be a part of this market, but at the same time cannot be seen as an independent market. It is a subset of scientific communication as a whole.

All four market forces are decisive for the rate of "research capital" return. Such rates of “research capital” return cannot be defined for any possible, incomplete subset of the entire market. As a consequence, one cannot separate modes of applicability from modes of accessibility, analyse information independently from the other forces, or even separate the actor pair into an author's market and reader's market.

Figures 1 and 2 illustrate the role of intellectual capital, confirming intellectual capital as a most important engine of societal development. At the same time it shows that there is a point of friction between intellectual property at the individual's level as opposed to the institutional level, the level of a (national) network or of an entire community. This has consequences for the certification function and raises some questions on the issue of ownership within the market, as will be discussed below.

The forces and functions together provide a useful description of the dynamics of the market as a whole, or the value created in the market. This description replaces the familiar linear value chain that does not do justice to the inherent multidimensional nature of the feedback system within the market.

5. Future developments

In the previous section we have developed a structural model of the market based on four forces of complementary pairs: the actor (author/reader), accessibility (availability/retrievability), content (questions/answers), and applicability (science/technology) force. This model emphasises a market driven, and not a technology driven, development, and in particular the empowerment of the market's generic stakeholders: the actor force.
Furthermore we described the relations between the main functions in scientific communication.
For an analysis of a future development in the market two questions come to the fore:
how will these functions develop?
do we need in the market a new division of functional tasks or a new functional division?

The first question has already been discussed in the previous section.

5.1 Strategic repositioning?

In this section we will focus on the second question. This is a question to a future structure and organisation of the market. We noted before that in the present market the principal stakeholders have outsourced a number of functions or tasks to other stakeholders such as publishers, libraries, agents, etc., or "insourced" to institutions such as societies, universities or research institutions. This accounts in particular for the external functions of registration (publisher, society) and archive (publisher, library), and the logistics aspects of the internal certification function (publisher, society).

We have shown that changes will be rational as opposed to paradigmatic. This means a change at the structural level resulting from function development (leading to increased added value) rather than a tactical development. We adhere to structural continuity for reasons outlined above in section 3. This means that the present system will evolve in a rational way with the developments in the market.

Recognition to be received by the individual, the research institution and the funder, be it a national or a transnational funder is key to these future developments. Following Merton (16) we realise that “a concern with recognition is symmetrical to a concern with advancing knowledge”.
Strategic research implies a new entrepreneurial regime for the research institutions. This means that the recognition depends on the applicability of research results. This demand for applicability will add an external component to

recognition. No doubt, this will affect the balance of forces in the market as it potentially leads to other choices in answers and questions, and sets other conditions for the use, and availability and retrievability of research results as a whole. These developments will determine how we will perceive the certification function. Changes in the certification function then automatically translate into changes of the registration and archive functions. This will affect the possible degree of outsourcing.

These developments may well lead to conflict, and some literature (5) mentions an "information crisis". The present analysis based on structural continuity may provide solutions to this perceived crisis.

5.2 Methodology

The present structure and organisation of the market have been seen to have a high degree of outsourcing of the external functions to other stakeholders in the "knowledge industry". These functions are performed mainly at the operational level and add only restricted intellectual value in the selection and processing of information.

The knowledge industry is a complex network of different stakeholders of authors and readers, organised in different kinds of research institutions, of libraries, societies, publishers, intermediaries such as subscription agents, and not least of the enabling industry and software houses. In this context we also see a development that the institution's departments of computer technology create alliances or even merge with the institution's libraries.
This network is characterised by a high degree of subsidiarity: the stakeholders enjoy a high degree of mutual strategic interdependence. The outsourcing concerns primarily the transfer and the management of content in the market, i.e. it is focused on accessibility in the market.
An issue is if this task of facilitation management should not be reintegrated into the market as we have seen that in an electronic environment we cannot conceptually separate accessibility from applicability and content. The trend in the market does not allow a simple operational separation either.
This is consistent with the development of strategic research with its dynamics emphasising problem finding and applicability over curiosity (section 2). Its focus on transdisciplinary research requires not only transfer of explicit knowledge, but also transfer of implicit knowledge. This lends a strong argument to reintegration, as it adds a new dimension to applicability of research and thus integrity in communication. No doubt, such reintegrated or comprehensive scientific communication services will be dynamic, not least for the "strategic research enterprise", as this enterprise will seek optimal return on research capital investment. Intellectual capital is key to this development.

5.3 Organisational Consequences

Knowledge is a virtual product, as being immaterial in itself, but looking real, and certainly having some very real consequences (29).
Scientific communication nowadays means electronic communication or electronic dissemination of "knowledge". This implies a virtual carrier for the virtual product, making use of a virtual memory. The question seems therefore legitimate if a virtual organisation should not be the appropriate, new organisation for the market (30, 31).

We follow the usual definition of a virtual organisation (29): a virtual organisation is a special case of an organisational network which is an identifiable whole vis a vis external stakeholders. An important characteristic of a virtual organisation is its distributed ownership. This distributed ownership distinguishes it from a co-operative conglomerate. A virtual organisation is thus mainly representing a balance of forces in the market.
As illustrated in Figure 1 and 2, it seems that the scientific communication market as a whole qualifies as a virtual organisation. The market shows aspects of distributed ownership. However, this conclusion is not correct if we define the market as the 'information industry" i.e. limited to the presently outsourced accessibility force of the entire market. This "information industry" is only a separate, outsourced and incomplete operational subset of the entire market. An analysis of the communication market on this basis will necessarily lead to invalid conclusions. Adherence to this organisational model may well lead to inflexibility in the development of the entire market.

Looking back at the historical development of the scientific journal as the vehicle for scientific communication, we see that the Royal Society of London, and other societies for that matter, represented a virtual organisation. In particular, as the research enterprises of that time were almost tautological with individual researchers, or small groups of researchers. Indeed, all forces in the market and all functions are integrated in the concept of the society with its members and institutions.

If we include in the market not only the transfer of information after the research process, but also the exchange of all kinds of information during the research process, e.g. in round-robin experiments, we can conclude that the scientific communication market, including all its partners, qualifies as a virtual organisation. It is consistent with the used definition of scientific communication to include all kinds of information.

The essential point is that if we also include information exchange during the research process, we consider communication within the entire research process: research and communication are viewed as parts of one organisation. If we limit ourselves to information exchange after the research process only, and this would be inconsistent, we must see communication and research as two distinct

organisations. In the latter case, communication is purely restricted to the functions; in the former case, we also consider the transactions between the functions.

One (virtual) organisation implies reintegration of those functions, and thus tasks, that are presently outsourced to "external stakeholders".
Reintegration responds to the stronger needs for new ways of return of research capital investment that are implicit within strategic research.

The question then arises if a new division and separation of functions is feasible. The present discussion illustrates that scientific communication as a whole cannot be organised independently from the research market if we take into account the conditions imposed by (strategic) research.
What can, and thus probably will, be organised independently is the communication network, i.e. the technological network, including information of a variety of nature and forms. This will be a distributed network and its core will be a distributed archive as discussed in section 4. The main tasks that presently can be foreseen for such a network are content (question/answer), storage and management of communication (availability/retrievability) and structure of communication (a condition for applicability). It has been proposed that a modular structure for scientific articles will replace the present linear structure (4b). Such a modular structure is supposed to strongly enhance the accessibility and thus applicability of elements of information and to allow a seamless and smooth integration with modules of other articles, or other information sets and collections.

These developments require a reorganisation of the knowledge industry and consequently a new division of tasks and responsibilities between the stakeholders. Following the conditions of a virtual organisation of such a unified, distributed system, strategic management needs to be clearly separated from operational management. This is an important issue for all stakeholders concerned.
It will call for new alliances or consortia between the stakeholders, where they presently form separated subsets or groups within the market.
For a real virtual organisation this would further imply co-operation within a somewhat nomadic context, without a strict hierarchy and not allowing "sedentary" relations (29) as boundary conditions for such alliances. These conditions carry important consequences for the present stakeholders in the "knowledge industry" and in particular for the stakeholders of the more restricted "information industry".
The above implies a new assessment of the distribution of ownership in such an organisation as content and applicability, as we have seen, are major forces of this distributed communication network. Content ownership can then not be seen as restricted to ownership of content transfer after the research process, and unrelated to its applications.

5.4 What is scientific communication?

In the above we have discussed scientific communication in its relation to the (strategic) research process and to scientific knowledge. As a consequence we cannot ask the question "what is scientific communication?" in isolation. We should ask the question "What is science and what is scientific knowledge? How do they relate?"

We will not be able to give an answer to this question. However, in this article we have discussed the relation between strategic research and scientific communication, and the trends in these processes. In doing so, we have taken the view that science policy or research policy becomes more and more an innovation planning policy resulting in strategic research. In strategic research, problem finding has been seen to play an even more important role than it did before (13).

Scientific communication then serves to facilitate strategic research.
Taking the approach of structural continuity we have touched on a number of methodological aspects of scientific communication and formulated some new aspects of the market, of its functions and of its organisation.

The discussion has left quite a number of aspects untouched and resulted in many questions that need to be answered further. These questions are to be addressed within the framework of a (strategic) research programme on scientific communication also taking onto account the observed developments in research and education.

Nevertheless, it seems safe to conclude that the general direction that research policies, and thus, research, have taken make the process of reintegration and reorganisation of the scientific communication market a necessity. This may then in turn lead to new schemes of dividing this market into more or less separated entities. This makes strategic repositioning within the scientific communication market inevitable!

6. Summary and conclusions

This article provides an analysis of the transformation of the linear scientific information chain into a scientific communication “network”. An attempt has been made to develop a methodology to investigate this transformation. The resulting methodology enables us to arrive at a set of observations, conditions and results for this transformation.

We analysed the phenomenon of strategic research (section 2) which adds "economy of scope" to scientific research. Science policies all over the world result in transforming research institutions to so called "centres of excellence" which will become transnational, entrepreneurial institutions. The emergence of these institutions leads to further consequences for their funding. Strategic research has been seen to be society driven.

For our discussion of scientific communication, intellectual capital, and thus internal research time, appears as the crucial parameter of scarcity. “Return of strategic research capital investment” is the overriding issue for the emerging research institutions, and this means to retain control over their intellectual property. As corollary, it becomes evident that a distinction between industrial research and academic research becomes even more blurred. Within this context of strategic research we touched on a number of familiar questions (11):

- what does research production consist of
- who are the actors and what is their competence
- how can we define the underlying dynamics
- how is agreement being obtained between the actors
- what forms of organisations are assumed, and
- how can we describe the overall dynamics?

In this article we restricted ourselves to the communication aspects of the underlying developments.
We have established that strategic research calls for new forms of knowledge management for the individual researcher as well as the research institution (section 3). Within this context we have formulated some questions on the future role of publications within research and the type of publications needed. We have seen a shift in focus from e.g. data collection to data validation and clustering as an example that the present rate of production of research needs alternative ways of certification of research information, as otherwise strategic research may fall the victim of the so called information crisis. Such a crisis may well retard the research progress as a whole.
One of the conditions for scientific communication is that it should provide effective and efficient ways of filtering new research results that allow proper "ageing" of research models and theories. Thus certification should be subject to the conditions of strategic research for reasons of consistency.

The information technology developments have been seen to lead to further empowerment of the key stakeholders in scientific communication: the author and the reader. As such, one could argue that there is a genuine technology push.

For our analysis of the transformation of the linear information chain into an interactive scientific communication “network” we have adopted a methodology leading to a structural analysis rather than a tactical analysis (section 4). This is achieved by describing the scientific communication market by four forces of complementary pairs: the actor, the accessibility, the content, and the applicability pair.

These forces allow an overall description of the dynamics of the market. This description provides a frame for the various aspects of time, space and action (23) that are relevant within this context.
It further reflects the unified nature of this market that is essentially a multidimensional feedback market system. This unified nature is reflected in the scientist's desire for one unified collection of research achievements. This collection is then distributed over many subcompartments, and results in a number of organisational conditions.
Within this new "value network" of forces we have defined a set of four functions for scientific communication. These functions are the registration, archive, awareness and certification function. The developments of these functions in an electronic dissemination regime have been discussed. It was seen that the present focus of development is on the registration and the archive function, where in particular the development of the archive function raises organisational issues. It is expected that within the context of strategic research the certification function will require fundamental rethinking.

The observed development of the value chain for scientific information to the scientific communication value “network” of a distributed system has led us to the question of a future organisation of this market (section 5). We have seen that within this context a number of aspects characteristic to the “virtual organisation” is of relevance.
In particular, with so many stakeholders involved, and given their widely different roles within the system and the conditions imposed by knowledge management within strategic research, the ownership issue becomes a complex one. The virtual organisation seems promising in providing some answers and rules for a configuration of distributed ownership, thereby reducing the stated complexity. We have noted the desire for a unified collection and from our discussion it follows that this is only achievable under conditions of distributed ownership and complementarity between all stakeholders involved.
These changes could possibly lead to a conflict or a crisis within the present information industry. The methodology used produces some solutions, provided the stakeholders express a clear interest in adhering to the new conditions

imposed by the forces in the market.
A central issue is to come up with a solution for the strategic management of the distributed scientific communication market. This means finding the right balance and interface between private and public interests, and consistent with the main aim of serving strategic research with its particular emphasis on applicability, intellectual capital and, as a consequence, integrity of its communication. This requires a broad, international programme inviting the majority of stakeholders, private and public, in defining, implementing and executing a co-ordinated set of projects each focused to test different issues and aspects of the strategic repositioning of the scientific communication market.

More research has to be done, because many explorations and observations in this article can only be considered as first, initial attempts in developing a methodology for a research programme on scientific communication. Such a programme should be seen within the context of strategic research, and should develop and be based on clear heuristics.
We make a plea to develop such a research programme as an independent research discipline. We feel that this research programme is needed as our research progress- and thus societal progress-depends so much on the ability to manage and to communicate scientific knowledge in an effective and efficient way.

Research issues that emerge are issues related to the present market transformation. Research should aim to develop a clearer picture of forces in such a future market and of the applicability of the virtual organisation to further develop each of the communication functions. Emphasis should be on the certification and awareness functions as these are decisive for the applicability of our research efforts. This research will involve technological communication developments such as replicable knowledge modules, search agents representing research profiles, editorial research and scientometric/bibliometric research (32) just to name a few aspects. With respect to the latter, it is expected that electronic storage and dissemination will add new dimensions and will allow new dynamics to scientometric/bibliometric research. With respect to the archive function conditions for transparency need to be further explored.

The research programme should allow for empirical testing of its results, which seems feasible within an electronic environment allowing dynamic simulations.
Key in such a research programme will be to analyse and develop new structures and types of publications. A modular structure has been mentioned and is now being investigated, and the distinction between formal and informal communication might be lifted.
If, and how, this will happen is a question that is relevant to the functioning of the entire system. Connectivity of communication and its auxiliary tools such as identifiers, indexing and classification need to be considered as well.
In short, we need a research programme of communication incorporating relevant elements of science. This programme may also well border on aspects of meta-

communication, such as meta-data, and some aspects of meta-science or science of science as well.

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Reference list

1 M. J. Mahoney, in "Psychology of Science", ed. by Gholson B., Shadish Jr. W.R., Niemeyer R.A., Houts a.c., Cambridge University Press, (1989)

2. D.K. Simonton: ibid

3. G.J. Stigler: "Essays in the history of economics", University of Chicago Press, (1965)

4a. J.G Kircz and H.E. Roosendaal, "Understanding and shaping scientific information transfer", UNESCO Expert conference on electronic publishing, Paris (1996)

4b. J.G. Kircz: Modularity: the next form of scientific information presentation. Journal of Documentation, 54 2 (1998), pp. 210-235.

5. See e.g.
P. Ginsparg, Winners and losers in the global research village: http://xxx.lanl.gov.blurb/pg 96 unesco.html

S. Hanrad, The paper house of cards (and why it's taking so long to collapse), Ariadne, 8, March 1997; http://www.ukoln.ac.uk/ariadne/

A.M. Odlyzko, Tragic loss or good riddance? The impending demise of traditional scholarly journals. Intern. J. Human Computer Studies 42 (1995)

6. "Science in Context", ed. Barnes B. and Edge D., The Open University Press (1982)

7. "Inside Academia", ed. Maassen P.A.M. and van Vught F.A., De Tijdstroom BV Utrecht (1996)

8. M.F.J. Pijnenborg, "Onderzoeken, onderwijzen, ondernemen", Elsevier Science, Amsterdam (1993)

9. B. Readings, "The University in ruins", Harvard University Press (1996)

10. W.J. McGuire, in "Psychology of Science" ed. by Gholson B., Shadish Jr. W.R., Niemeyer R.A., Houts A.C., Cambridge University Press, (1989)

11. See: S. Jasanoff, G.E. Markle, J.C. Petersen, T. Pinch, "Handbook of Science and Technology Studies", Sage Publications (1995)

12. G. Radnitzky, in "I. Lakatos and theories of scientific change", Boston Studies in the Philosophy of Science, Vol. III, Kluwer Academic Publ. (1989)

13. J.P. Bernal, "Science in History", MIT Press (1965)

14. I. Lakatos, "The methodology of Scientific Research Programmes" Philosophical Papers, Vol. 1
ed. Worrall J. and Curie G., Cambridge University Press (1978)

15. G. Panhuysen, Theory and Psychology 5 (2) 1995, p. 171-194

16. R. Merton, "The Sociology of Science: Theoretical and Empirical Investigations", University of Chicago Press (1973)

17. M. Gibbons, "The new production of knowledge: The dynamics of science and research in comtemporary societies", Sage Publications (1994)

18. J. Ziman, "Prometheus bound: Science in a dynamic steady state", Cambridge University Press (1994)

19. A.G. Gross, "The Rethoric of Science", Harvard University Press (1994)

20. C.D. Andriesse, "Titan kan niet slapen", Biography of C. Huygens, in Dutch, Uitgeverij Contact, (1993)

21. P. Geurts and H.E. Roosendaal, "Combining qualitative and quantitative methods in Strategic Market Research using a heuristic model", to be published.

22. H.E. Roosendaal, "Scientific Communication and the Science Process", Proceedings of the International Summer School on the Digital Library, Tilburg, The Netherlands, August 1996, ed. J.G. Van Luyt-Prinsen and E. Meijer, Ticer B.V. (1996), p. 1-12.

23. H.E. Roosendaal and A.P. de Ruiter, "The journal at the crossroads of developments in scientific information and information technology", Paper presented at Conference in Helsinki, 1990

24. C.G. Jung, "Gesammelte Werke", Sechster Band, Rascher Verlag, Zürich (1960)

25. H.D. Daniel, "Guardians of Science", VCH Weinheim (1993)

26. J. Zinn-Justin, Invited Talk at CRISP '97, Oldenburg, http://www.physics.mcgill.ca/_karttune/crisp97/

27. K.R. Popper, "Conjectures and Reputations", Routledge (1991), first published by Routledge and Kegan Paul plc. (1963)

28. A.F.J. van Raan, "The future of the quality assurance system: its impact on the social and professional recognition of scientists in the era of electronic publishing", Journal of Information Science, 23 (6) 1997, pp. 445-450

29. J.E. van Aken, invited talk at ESTIEM conference, University of Twente, January 1997

30. U. Hofmann, Nachrichten für Dokumentation 47, (1996), 335-338

31. H.E. Roosendaal, invited talk at ESTIEM conference, University of Twente, January 1997

32. H.E. Roosendaal, Roles of Bibliometrics in Scientific Communication, Invited talk at The Fourth International Science and Technology Indicators Conference, Antwerp, Belgium, October 5-7, 1995. Research Evaluation, 5, 3 (1995),p-237-241