How to distinguish scientific fields:

An empirical analysis of field differences

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Abstract

Knowledge production is increasingly becoming the main driver for economic growth of modern western countries. Because of the shift to a knowledge based economy, knowledge production has changed over the past two decades. This knowledge transition has lead to the assumption that the differences between scientific fields are growing as well. These fields can vary in several aspects. There is no consensus of what exactly these aspects are, although the last two decades several attempts have been made to understand, analyze and explain these differences between fields. Examples of these analyses are the notion of Mode1 and Mode 2 knowledge creation (Gibbons et al., 1994), the concept of a triple helix between universities, government and industry (Etzkowitz and Leydesdorf, 1997), the model of Pasteur's quadrant (Stokes, 1997), intellectual and social organization of sciences (Whitley, 2000), the shifts of search regimes (Bonaccorsi, 2008) and the older distinction between hard and soft sciences. However, possible correlations among concepts of these theories are never grounded with empirical evidence. The aim of this research is to find which concepts and the relationships between these concepts that distinguish scientific fields are most useful for field differentiation. Hence the research question: *Which dimensions and which correlation among these dimensions are most useful for distinguishing scientific fields?* The empirical data is derived by distracting scientometric indicators from scientific journals that represent 21 scientific fields which are qualitatively analyzed. There are six dimensions found in the theories being: collaboration between scientists, presence of science, industry and government, globalization, growth of knowledge production, knowledge accumulation and divergence topics. Each theory presumes a correlation between two or more of these dimensions. The results show that the more modern theories (the mode1 and mode 2 knowledge creation theory, the triple helix theory, the intellectual and social organization of sciences theory and the search regimes theory) cannot be validated by the empirical evidence. The correlations between dimensions as proposed by the more traditional theories of hard and soft sciences and Pasteur's quadrant are more supported by empirical evidence and are thus more useful for distinguishing scientific fields. However, these do not include the transition in knowledge creation of the last two decades. This means that none of the modern theories did yet grasp the precise elements and correlations that distinguish scientific fields in the time that knowledge development is in transition. Furthermore, this study confirms that knowledge production is indeed changing, but it is hard to grasp which dimensions and which interrelation among these dimensions distinct scientific fields.

Keywords: scientometrics, scientific fields, knowledge transition, correlation dimensions, Mode 2, Triple helix, Pasteur's quadrant, intellectual and social organization of sciences, search regimes, hard and soft sciences.

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Introduction

Knowledge production is increasingly becoming the main driver for economic growth of modern western countries instead of the production of goods (OECD, 1996). Since the 1970's, these countries have more and more been suffering from problems like stagnation, inflation and unemployment. They could no longer compete with upcoming economic forces like China and India in terms of productivity because of several favorable conditions like lower labor costs in those countries (Skipper and Spencer, 2005). Therefore modern western countries have shifted the main focus for economic growth to the production of knowledge. This has led to the occurrence of the term 'knowledge based economy' which entails that modern western countries acknowledge the production and organization of technology and knowledge as an important growth factor (OECD, 1996; Cooke and Leydesdorff, 2006).

The shift to a knowledge based economy has been an important factor of changed knowledge production over the past two decades (Martin, 2010). There have been several studies that indicate a variety of changes, such as the growing importance of strategic goals within science systems (Irvine and Martin, 1984) and the focus on knowledge creation which can be applied (Böhme et al., 1983; Gibbons et al., 1994). This has resulted in a closer connection between science and technology than before. As a consequence, boundaries of scientific fields are diminishing because collaboration with other fields or institutes is necessary to meet the societal needs for applied knowledge. The development of science is less developed within individual scientific fields, but becomes more inter-, multi- or transdisciplinary (Martin, 2010). In addition, research and knowledge creation are no longer only carried out in traditional universities and public research laboratories, but in a great variety of institutions and contexts (Martin, 2010; Hessels and van Lente, 2008). These changes among other changes lead to the assumption that the differences between scientific fields are growing (Heimeriks and Vasileiadou, 2008).

In parallel with this transition in knowledge production and growing differences between scientific fields is the emergence of policies to stimulate the knowledge creation. Since knowledge production is becoming such an important economy driver, a form of guidance to improve the production of knowledge is necessary. Governmental stimulations to enhance the knowledge based economy should deliver benefits to society and not only provide basic knowledge, which has less value for society. This policy implementation is not limited at the macro level of governmental decisions. Also on lower levels such decisions must be made, for example how universities should divide research money over different faculties or which research projects should get the most attention.

However, performing successful policy proves to be difficult. A main factor of this difficulty is the growing differences among scientific fields of knowledge production. There are many different scientific fields in which knowledge can be created, but these fields can vary in several aspects. There is no consensus of what exactly these aspects are, although the last two decades several attempts have been made to understand, analyze and explain these differences between fields. However, all these attempts are not uncontested. Examples of these analyses are the notion of Mode1 and Mode 2 knowledge creation (Gibbons et al., 1994), the concept of a triple helix between universities, government and industry (Etzkowitz and Leydesdorf, 1997), the model of Pasteur's quadrant (Stokes, 1997), intellectual and social organization of sciences (Whitley, 2000) and the shifts of search regimes (Bonaccorsi, 2008) and the older distinction between hard and soft sciences. This large pile of different available models and frameworks is the result of an ongoing debate of which concepts exactly lead to the differences among fields.

Since there is no consensus about the relevant concepts in these theories and they are all not uncontested, the question rises whether it is justified to take these theories into account when aiming for policy to stimulate a knowledge based economy. The lack of empirical evidence for these theories does not help their reliability either.

The growing differences between scientific fields as mentioned by Heimeriks and Vasileadou (2008) can be influenced by several aspects, for example the number of new keywords or new publications. The theories mentioned above often point to the differences of dimensions between scientific fields. For example, the theory of mode 1 and mode 2 knowledge creation (Gibbons et al., 1994) mentions five dimensions that distinguish mode 1 and mode 2 sciences. However, the lack of coherence of these dimensions is probably the largest threat to this concept (Hessels and van Lente, 2008). Other theories mention that other concepts and other correlations of the concepts lead to differences between scientific fields. The development and interactions of these concepts could be a very important reason why scientific fields are different. Since different theories mention different concepts and correlations it is not clear which concepts are useful for distinguishing scientific fields.

Summarizing, successful policy implementation for the stimulation of knowledge development proves to be difficult. The heterogeneous characteristics of scientific fields make a 'one size fits all' approach not suitable since it would benefit one field but could hinder another field (Bonaccorsi, 2005; Asheim and Boschma, 2006). Different knowledge dynamics of scientific fields lead to different responses of particular fields on similar policy interventions (Heimeriks, 2009). The various concepts and the correlation among these concepts as proposed by theories in each scientific field might be a very important factor why these fields respond differently. Since empirical evidence for differences among scientific fields is lacking and the influence of the correlation among multiple concepts within theories are not yet researched, the aim of this research is to find which concepts and the relationships between these concepts that distinguish scientific fields are most useful for field differentiation. From the concepts, dimensions which can be measured will be derived. This is based on empirical data of multiple dimensions, leading to the following research question:

Which dimensions and which correlation among these dimensions are most useful for distinguishing scientific fields?

The concepts that play an important role in differences between scientific fields are studied by means of a literature study of existing relevant theories about knowledge development. The correlation among these concepts will be studied with empirical data which will be attained by means of scientometric data and indicators. Scientometric indicators have as purpose to understand what the main features of science and innovation are, how they interrelate, and how these features and their relationships change. Scientometric indicators are widely used in policy documents and in science, technology and innovation studies (Heimeriks and Leydesdorff, 2011). The study will be based on 21 different scientific fields which are selected to be representative for the current scientific landscape (central tendency journals). Furthermore, it can be checked whether the insights from the before explained existing theories of differences between fields of knowledge development and the trends they observe in knowledge production can also be found in hard empirical evidence. This will contribute to the existing insights of how knowledge development has changed over the years and how this has contributed to differences between scientific fields. Subsequently, the findings of this research can be used for policy measurements which can take the empirically derived distinctions into account in order to stimulate the desired knowledge based economy.

Justification

The growing differences between scientific fields of roughly the last 15-20 years as mentioned by Heimeriks and Vasileiadou (2008) increases the need for scientific field differentiation. As mentioned before, several studies have been done to distinguish different fields of science and explain the shift in knowledge creation, but these studies have several shortcomings, which will be explained in this section. An example of a distinction between scientific fields, which might be the most famous, is the notion of mode 1 and mode 2 sciences as developed by Gibbons et al. (1994). Mode 1 science is a disciplinary, university-based type of science that has always existed. They claim the rise of a more modern mode 2 science which focuses on multidisciplinarity, based on networks of distributed knowledge, and oriented towards problem solving and societal challenges. Both types of science can exist next to each other, giving a possible distinction between types of science. However, this theory is hardly validated with empirical evidence. Furthermore, it only provides a snapshot of the current situation while it is necessary to understand the dynamic changes over time in order to better understand the differences between fields and how they have come about.

Other methods to distinguish scientific fields are developed by Whitley (2000) and Bonaccorsi (2008). Whitley (2000) characterizes differences between scientific fields in two concepts: *1* - the degree of mutual dependence between researchers or fields in making competent and significant contributions to a body of knowledge and *2* - the degree of task uncertainty in producing contributions and evaluating knowledge claims. Bonacorrsi (2008) distinghuishes scientific fields as follows: *1* - the rate of growth, *2* - the degree of divergence (the direction of growth (converging or diverging) and *3* - the level of complementarity (the extent to which different human or material resources are needed, in addition to the intellectual resources). Both theories lack (internal valid) empiric evidence and they do not provide a dynamic picture of knowledge development. Another shortcoming is the focus on science only, whereas the connection between the level of science and the levels of research and society is neglected. According to Heimeriks (2009) these different dynamic levels influence each other. Because this interaction is different in each field, the scientific processes are not similar, resulting in differences among scientific fields.

Two other theories are the triple helix theory (Etzkowitz and Leydesdorf, 1997) and the theory of Pasteur's Quadrant (Stokes, 1997). The triple helix theory is about the interaction between the three sectors; universities, government research organizations and industrial laboratories. This theory provides an vertical level of disaggregation (i.e. the connection between science, research and society) and how this has come about in the last 15-20 years, but it also not grounded by empirical evidence. Pasteur's Quadrant is an addition to the classic separation of basic and applied science, in which an extra possibility for knowledge creation is included, namely research which aims both to produce new understanding and to develop a new application and thus meet some economic or societal need (Pasteur's Quadrant). This theory lacks empirical proof as well and neglects vertical disaggregation and dynamic compounds. Finally, the more traditional difference of hard (natural) and soft (social) is also a method for distinction of certain scientific fields. Attempts to ground this distinction have had limited success, although new leads to distinguish hard and soft sciences have been found by means of graphs in journal articles which correlates highly with the hardness of scientific fields (Smith et al., 2000). However, this is only researched for fields within psychology. Empiric evidence for distinguishing several scientific fields is not yet available.

Summarizing the available theories for field distinction, there are three factors missing which are very important when policy is derived from them. First of all empiric evidence is lacking in all theories. Policy should not be based on theories which are not validated by empirical proof. The second element that is missing in most theories is the focus on the level of science only, whereas research and society also influence knowledge creation. The last element missing is the static picture that most theories provide. When knowledge creation is in transition, which all theories acknowledge, especially the changing elements over time influence how scientific fields are different. This research aims at finding which dimensions and which correlations of these dimensions are most useful for distinghuishing scientific fields. Thereby, the three factors will be taken into account since (1) the elements will be researched by means of empirical data, (2) it will incorporate the level of research, science and society and (3) the elements will be researched over a time span of 15 years (1995 until 2009).

The results of this research can, in the first place, provide empirical data about the relevant dimensions which change and shape scientific fields. In the second place the assumed claims of correlations of dimensions as each theory propose can be empirically researched. Lastly, these results can possibly provide handholds for policy recommendation for stimulation of knowledge development. This is necessary because the 'one size fits al' policy does not stimulate each scientific field equally well.

The next chapter will elaborate and discuss the existing theories about differences in knowledge creation between scientific fields. From the concepts the theories propose, dimensions will be derived in order to measure the existence of the concepts and their correlations.

Theory

This chapter will elaborate on the existing discussion between different scholars and theories about the recent changes in the scientific fields and how they differentiate these fields. The different theories, which are identified in a literature study, will be explained and discussed. This discussion is based on the concepts and the correlation between these concepts that the theories provide and their impact on scientific fields. From these concepts, dimensions will be derived that make it possible to research the concepts and their correlations by means of scientometric indicators.

Theoretical discussion

This section will explain and discuss the various theories about knowledge development and field differentiation. As noted in the introduction, several distinctions between scientific fields have been made by different scholars. This section will elaborate on the following modern theories that acknowledge the shift in knowledge transition: Mode 1/Mode 2 (Gibbons et al. 1994), triple helix (Etzkowitz and Leydesdorf, 1997), Pasteur's quadrant (Stokes, 1997), search regimes (Bonaccorsi, 2008) and intellectual and social organization of sciences (Whitley, 2000). Also, a more traditional comparison will be discussed; the differences between hard and soft sciences.

Mode 1 sciences and mode 2 sciences

The first and most famous distinction of scientific fields is the notion of mode 1 and mode 2 sciences as developed by Gibbons et al. (1994). According to them, there is a rise from the old-fashioned mode 1 science to the modern mode 2 sciences. They claim that mode 2 knowledge creation is a new form of knowledge production which is more interactive and socially based than mode 1 knowledge creation. Mode 1 knowledge has always existed and mode 2 knowledge is a new form of knowledge creation which can exist next to mode 1 knowledge creation.

Mode 2 knowledge production has 5 main concepts that differ from mode 1. Table 1 shows a summary of the different attributes of mode 1 and mode 2 sciences. The first attribute that differs is that mode 2 knowledge is created in the *context of application* instead of academic context. Mode 1 knowledge can also be practically applied but these applications are always separated from the knowledge production by time and space. The second notion is that mode 2 knowledge is created by several fields instead of one field in mode 1 knowledge. This is called *transdisciplinary* knowledge creation and goes beyond interdisciplinary in the sense that the interaction is much more dynamic. A third important attribute is that knowledge is not only created within homogeneous traditional scientific institutions like universities and laboratories but the knowledge production occurs in more heterogeneous places, for instance research centers, government agencies, think-tanks, high-tech spin-off companies and consultancies (Hessels and van Lente, 2008). The involved centers are connected with each other so knowledge production does not occur in isolation but in mutual interaction. Another attribute is *reflexivity*. Mode 2 knowledge creation occurs with multiple different views in mind. Scientists are aware of the social implications of their work and take these from the beginning of their work into account (social accountability). The last attribute is *novel quality control*. Since mode 2 knowledge has a transdisciplinary character it is harder to determine 'good science', because this no longer is limited to the judgment of disciplinary peers and also social, economical or political criteria need to be assessed. Therefore, new forms to control the quality of the knowledge produced are needed next to the traditional peer reviews. This does not imply that mode 2 knowledge is of a lower standard (Hessels and van Lente, 2008).

Table 1: Differences between characteristics of mode 1 and mode 2 sciences according to Gibbons et al. (1994)

Mode 1 knowledge creation	Mode 2 Knowledge creation
Academic context	Context of application
Disciplinary	Transdisciplinary
Homogeneity	Heterogeneity
Autonomy	Reflexivity/social accountability
Traditional quality control (peer review)	Novel quality control

The main point that mode 2 sciences differentiate from mode 1 sciences is that the knowledge production is 'socially distributed'. Mode 2 sciences consist of more application based, temporary products and projects. They are more opportunistic and dependent on the needs of society. Therefore, presence of governments and industries within scientific fields is higher, because of the orientation for applications instead of academic knowledge. Governments can focus on certain needs by means of funding scientific projects dealing with these needs. This can also lead to more collaboration between scientists, in order to fulfill these needs in a shorter term. Industries are application based since normally their main goal is profit making and basic knowledge does not directly yield money. Furthermore, the existence of more small and shorter projects in mode 2 sciences lead to less consistency in the topics and thus to a higher diversity of topics than in mode 1 sciences. Lastly, small individual projects lead to less accumulation of knowledge since the projects do not build on earlier projects but stand on their self. Scientific results are cumulative when empirical theories and laws are based on earlier work and thus expand and unify earlier work.

The notion of mode 2 knowledge creation as developed by Gibbons et al. (1994) is not without criticism. Some scholars don't agree that mode 2 knowledge is new but has existed for a longer time than mentioned by Gibbons et al. (Weingart, 1997). Criticism is based on a theoretical basis but also on empirical data. The lack of empirical evidence for the rise of the different dimensions is mentioned by Hessels and van Lente (2008). Accordig to gibbons et al. (1994): "These attributes, while not present in every instance of Mode 2, do when they appear together have a coherence which gives recognizable, cognitive and organizational stability to the mode of knowledge production". This means that the attributes do not always appear in mode 2 sciences which make the assumption of the coherence of the attributes questionable. In this research, we can empirically explore whether the presence of the dimensions indeed mutually exist in mode 2 sciences. Still, the theory is supported by many scholars, proven by the fact that the article of Gibbons et al. (1994) is more the 1000 times referred to in scientific articles. Since it has also influenced science, technology and innovation policies (Hessels and van Lente, 2008) the distinction of mode 1 and mode 2 can provide important elements that differentiate scientific fields.

The Triple Helix

The triple helix theory (Etzkowitz and Leydesdorff, 1997) concerns the influence of an interrelation between universities, government and industrial laboratories on scientific fields. According to the authors, this link is new and has been established during the past 15-20 years. Before, this relation did not exist and the three institutions worked separately. As a consequence of this interrelation, the boundaries have diminished and there is more interaction and overlap of the sectors. This can for example be seen by the growing direct contribution of universities to meet the needs of the government, industry and society. Universities no longer only teach and research, but also contribute to society. These three missions are also picked up by emerging entrepreneurial universities, which Etzkowitz and Leydesdorff (1997) call the 'the second academic revolution' (the first academic revolution occurred when universities began to do research as a formal mission, next to teaching).

Similarly to the mode1/mode2 theory, the triple helix theory suggests there are differences between fields when it comes to the presence of governments and industries. Also the context of application is in both theories accepted. Universities are more contributing to society and in fields with a high presence of the government and society this contribution is even higher, since there is more interaction. A higher presence of the government and industry leads to a less global character of the scientific field, since they are more locally oriented. Governments mainly focus on improving regional or national regions. Industries that participate within scientific fields are also often regionally based, since global multinationals often have their own in-house research and development teams and thus do not contribute to knowledge production of a field.

This conceptual framework of the triple helix is not uncontested, some scholars claim that the theory is not new and there are doubts whether it is a model that adds to our understanding of knowledge production and exploitation. However, it is still a theory that emphasizes mutual dependence of different actors, which could be an important element that differentiates scientific fields.

Pasteur's Quadrant

This theory elaborates on the classic view that science policy was based on the dichotomy between either basic or applied research. According to Stokes (1997) this dichotomy should be expanded to a two-by-two matrix. The matrix exists of the two classical quadrants in which the first is based on research that aims at generating knowledge but not to develop new applications (Bohr's quadrant). This quadrant includes fields that are purely focused on research with little concern for social use, like high energy physics or psychology. The second quadrant consists of research that aims at developing new applications but creates little new knowledge (Edison's quadrant). Fields belonging to this quadrant consist of applied science and technology for social use, like medicine and diseases. Stokes adds Pasteur's quadrant in which both new knowledge and new applications for societal needs are created. Fields are for example nanotechnology and genomics. A fourth quadrant receives less attention and is about science that creates neither; examples are work on taxonomy and curation (Martin, 2010). Table 2 shows this matrix, as developed by Stokes (1997).

Table 2: Stokes' model of scientific research (Stokes, 1997).

	No new applications	New applications
No new knowledge		Edison's quadrant
New knowledge	Bohr's quadrant	Pasteur's quadrant

According to this model, new knowledge created in scientific fields that fall in Pasteur's quadrant are both oriented on the creation of new applications as well as the creation of new knowledge. The application based view is in line with the mode1/mode2 knowledge creation and the triple helix theory. This means that there is a high presence of the industry in fields that fall in Pasteur's quadrant, because industries turn science into (technological) applications. Furthermore, the scientific fields that fall in Pasteur's quadrant also have new knowledge creation in the form of knowledge accumulation. This is in contradiction with the mode 2 knowledge theory, because Gibbons et al. (1994) claim that scientific fields that belong to mode 2 sciences have a low knowledge accumulation due to the short term orientation of these fields. Fields that fall in Pasteur's quadrant have both a high presence of the industry and a high knowledge accumulation.

This theory is criticized for not providing an analytical framework but more a descriptive taxonomy. Secondly it is hard to define applied knowledge, since also creation of basic knowledge can ultimately provide societal benefits, especially in the long term. This means that almost all science falls in Pasteur's quadrant. Nevertheless, this shift can also be an important element for field differentiation.

Search regimes

Bonaccorsi (2008) developed another method for science distinction, which is based on shifts in 'search regimes'. A 'regime' is 'a consistent set of dynamic properties of the search processes in a scientific field or discipline. He bases the distinction on three factors: *1* - the rate of growth, *2* - the degree of divergence, or the direction of growth (either converging or diverging) and *3* - the level of complementarity (the extent to which different human or material resources are needed, in addition to the intellectual resources). On these differences he bases four different categories of science regimes (table 3).

Table 3: The four categories of Bonaccorsi with examples

Categories	Examples
1. Low diversity/low complementarity	Traditional chemistry
2. High diversity/low complementarity	Mathematics
3. High diversity/high complementarity	High energy physics
4. High growth, high diversity and high complementarity	Biotechnology, computer science, nanotechnology

According to bonaccorsi (2008), the fourth category includes the 'new leading sciences', which are characterized by a high growth rate, divergent dynamics of search with new hypotheses continually generating new research topics, and new complementarities in which especially wide ranged cross disciplinary competencies are needed. These sciences are born in the twentieth century and developed after the Second World War and became extremely prolific in the last quarter of the 20th century (Bonaccorsi, 2008).

According to this theory, scientific fields that fall under new leading sciences have a high growth of knowledge development. Furthermore, the diversity of the new topics is high, leading to a high variety of keywords. Another element of the theory is that the collaboration is high, because of the high level of complementarity. These elements characterize new leading sciences.

This theory is still in a conceptual state, but the author thinks it suggests a number of promising research directions (Bonaccorsi, 2008). The theory is more substantiated by empirical data than the other theories, but the data for growth and diversity is only based on scientific words, which hampers the internal validity. Furthermore, it is only tested for a few scientific fields.

Intellectual and social organization of sciences

Another method for distinguishing scientific regimes is developed by Whitley (2000) who characterizes differences between scientific fields in two concepts: *1* - the degree of mutual dependence between researchers or fields in making competent and significant contributions to a body of knowledge and *2* - the degree of task uncertainty in producing contributions and evaluating knowledge claims. Mutual dependence refers to the dependency of scientist on other scientists in scientific fields. This dependency can consist out of reputation, access to resources and on the results and contributions to the field. A high mutual dependency means a high degree of collective identity, a high competition between researchers, a low standard for local and individual autonomy from collective goals and a formalized communication system. Task uncertainty is about the uncertainty of working techniques, intellectual priorities and research topics in the field. A high uncertainty means less standardized research procedures, and a harder comparison of the results.

Whitley (2000) argues that the differences between scientific fields are caused by these elements. Fields with a high mutual dependency and a low task uncertainty can be characterized as fields that are aware of the progresses that are made within the field. For instance biochemistry has a high mutual dependency and a low task uncertainty since all scientists know what is happening in the field and what different institutions are doing. This leads to a strong competition in which is known what has to be achieved in order to be the first with new findings. So these fields have a lot of collaboration in order to accomplish this. Furthermore the knowledge accumulation is high since new knowledge is often based on earlier work. Therefore, the topics are converging and new keywords are the similar throughout the time.

On the other hand, there are fields that are characterized as having a low mutual dependency and a high task uncertainty. An example is innovation studies, in which the scientists are less aware of what is happening in the field. There are more different knowledge claims that can contradict each other, so there is less consensus. In these fields, the collaboration between scientists is thus lower. Furthermore, the knowledge accumulation is lower and the topics are more varied.

Hard sciences and soft sciences

This differentiation is a more classic approach of distinguishing scientific fields and is not in line with the knowledge development transitions of the last 15-20 years. Nonetheless, this distinction can be relevant because it makes a clear distinction between two types of knowledge creation which differ on several points. A crude comparison of these two sciences is that hard sciences are concerned with physical entities and soft sciences with living entities (Simms, 2011). When we go a step further we can typify hard science as science that can exactly identify and measure the subjects and what influence these subjects. The impact of gravity, for example, has been identified and measured and can easily be reproduced. Hard sciences can be compared with natural sciences such as physics and chemistry.

Soft sciences, on the other hand, can be typified as inexactly measurements of the subjects and the phenomena that influence them, for example life and society. 'Male domination' for example is more open for interpretation and this interpretation makes the science soft. Since there are many inconsistent variables that cannot be controlled, it is harder to analyze the data and reproduce it. Soft sciences can be compared with social sciences; examples are psychology and management sciences (Simms, 2011).

A big difference between hard and soft sciences is that hard sciences have more cumulative research results than soft sciences (Hedges, 1987). This means that hard sciences are often more based on earlier work than social sciences. It is a logical reasoning when accounting to the notion that hard science is more based on reproducible facts than soft sciences. Because of the reproducibility hard sciences can also be performed more globally. Soft sciences often need particular social occurrences or populations which make them more locally embedded. Hard sciences can be performed everywhere in any laboratory.

Dimensions

The theories all provide concepts that either agree or disagree with each other. Especially the correlation among different elements distinguishes scientific fields. From these theories we can derive six (measurable) dimensions in order to study the different elements. The following dimensions are derived:

1- Collaboration between scientists
2- Presence of science, industry and government
3- Globalization
4- Growth of knowledge production
5- Knowledge accumulation
6- Divergence topics

Each dimension will be explained and theoretically grounded.

Collaboration between scientists

According to the theory of mode 1 and mode 2 sciences (transdisciplinarity), the search regimes theory (the level of complementarity) and the intellectual and social organization of sciences theory (mutual dependency between researchers) there is an explicit claim of dependency of researchers on other researchers. This leads to the assumption that the degree of collaboration between scientists is an important factor which can be different among scientific fields and influence other aspects of knowledge creation as well.

Presence of science, industry and government

Another element which can be found in most theories is the presence of science, government and society within scientific fields. Especially the triple helix theory emphasizes this element, but also the theory of mode 1/ mode 2 sciences (heterogeneity, social accountability, novel quality control and context of application) and Pasteur's quadrant theory (both new knowledge and application development requires influences from different actors) directly or indirectly point to a collaboration between science, industry and government. Different scientific fields can thus have different influences from these actors which differentiates them.

Globalization

The rise of the internet has been a big change in the world in the past decades. Internet has been the biggest contribution to the globalization. This globalization influences scientific fields as well. The degree of globalization is a dimension that differentiates scientific fields. Fields in which the government has a high presence are often less global than fields in which governments are less participating. As explained, hard sciences also have a more global character than soft sciences.

Growth of knowledge production

Search regimes theory mentions this element as an concept but all theories agree that knowledge production is necessary for a scientific field to exist. In the end, knowledge production is the main goal of each scientific field (and the knowledge might be useful for application as well). However, the growth of knowledge production can vary between scientific fields.

Knowledge accumulation

This dimension is about the accumulation of knowledge which can be different among scientific fields. Knowledge accumulation is about the degree of created knowledge that directly comes out of earlier work and thus expand and unify earlier work. Mode 2 sciences are claimed to have less knowledge accumulation than mode 1 sciences due to the short term application focus. Pasteur's quadrant emphasizes knowledge accumulation as an element next to new applications. Whitley (2000) claims that fields with a high mutual dependency also have a higher accumulation of knowledge. Lastly, hard sciences are believed to have more knowledge accumulation than soft sciences (Hedges, 1987). As can be seen, knowledge accumulation is an important dimension for field distinguishing, agreed on by several theories.

Divergence topics

The last dimension is about the divergence of topics. The degree of divergence refers to the number of different topics used within a field. For the theory of search regimes (Bonaccorsi, 2008) this means that new leading sciences have a high variety of topics. The intellectual and social organization of sciences theory also differentiates fields based on how diverging the topics are. Therefore, this is also relevant a relevant dimensions when researching differences among scientific fields.

Summary / Correlation among dimensions

By combining the different theories with the different dimensions the following expectations for the results can be made. These are expectations of how different fields can be distinghuished according to each theory:

-Mode1/mode2 sciences (gibbons et al., 1994): Mode 2 sciences have more collaboration between scientists, have a higher presence of the government and industry and have a lower knowledge accumulation than mode 1 sciences.

-Triple Helix (Etzkowitz and Leydesdorf 1997): Scientific fields where the presence of government and industry are relatively high are less global.

- Pasteur's quadrant (Stokes, 1997): It is possible to make a relevant distinction between fields with both a lot of industry presence AND a high knowledge accumulation(Pasteur), fields with only a high presence of industry (Edison), fields with only a high knowledge accumulation (Bohr) and fields with both very low new knowledge creation and new applications.

-Search regimes (Bonaccorsi, 2008): New leading sciences have a lot of collaboration between scientists, a high diversity of topics and a high growth.

-Intellectual and social organization of sciences theory (Whitley, 2000): Fields can be distinguished between fields that have: high collaboration between scientists, high knowledge accumulation and a low diversity of topics and fields that have a low collaboration between scientists, low knowledge accumulation and a high diversity of topics.

-Hard/soft sciences: Hard sciences have both more knowledge accumulation and are more global than soft sciences.

Empirical data is used in order to test whether these expectations can be justified. This way the most relevant concepts of the theories can be studied. The next section will provide an explanation how the data is gathered and which methods are used to study this subject.

Data and Methods

The function of this paper is a evaluative research, because the correlations of the dimensions proposed by theories are evaluated and studied in order to find out which theories are most useful for explaining differences between scientific fields. To empirically research the dimensions and their correlation as found in the last chapter, a study will be conducted on scientometric data that will function as indicators for the six dimensions. Scientometric indicators have as purpose to understand what the main features of science and innovation are, how they interrelate, and how these features and their relationships change. From each investigated scientific field, a journal is chosen which best represents the field it belongs to (central tendency journal). This is based on its impact factor, the number of articles and the number of citations. Each journal used is the central tendency journal meaning that each journal will measure the average value of all journals from a specific field and will thus be representative for that field. This journal will provide the data about that specific scientific field. The journals are found on the ISI Web of Knowledge, which contains the world's leading scholarly literature in all sciences. In this database, together with Journal Citation Reports which is part of Web of Knowledge, scientometric data of scientific journals can be found and analyzed. From this site, relevant data from each journal in each field is gathered, which will help to indicate the different dimensions.

The sample exists of 21 different scientific fields which are selected in such a way that all theories can be categorized. This means there are mode 1 and mode 2 scientific fields, hard and soft sciences etcetera. This means there are a representative number of sciences that can be categorized for all the theories mentioned in the theory section. Furthermore, the data is collected for the time span of 1995-2009, resulting in data which can show a dynamic picture and it includes the period that knowledge has changed drastically according to the literature. This will result in a database including indicators which can be used to research the different dimensions and their correlation, which is needed to answer the research question.

The dimensions, as proposed in the theory section, will be researched by means of scientometric indicators that can be derived from scientific journals on the Web of Science. The dimensions will act as tools to measure the concepts that are assumed by the different theories. Table 4 gives an overview of the six dimensions and the indicators to measure these dimensions.

Table 4: Dimensions and the indicators

Dimension	Indicator
1- Collaboration between scientists	-Authors per paper
2- Presence of science, industry and government	-Percentage of journals with source: the public sector, industry or university
3- Globalization	-Countries per year -Stabilization countries -Percentage internationally co authored
4- Growth of knowledge production	-Articles per year
5- Knowledge accumulation	-Cited half life -Citing half life -Stabilization cited journals -Times cited

6 - Divergence topics	-Stabilization keywords

Next, a short explanation of each indicator for each dimension is given.

1- Collaboration between scientists

-*Authors per paper*: More authors per paper mean more collaboration between scientists. This will be measured by means of the average number of authors per paper per year and for each scientific field.

2- Presence of universities, industry and government

-*Percentage of journals with source: the public sector, industry or university*: when a higher percentage of all three institutions is present, the chances are higher that they collaborate more. This indicator will show in which fields which institutions are more active.

3- Globalization

-*Countries per year:* When the number of different countries is climbing, this means that the scientific field is performed more globally. This will thus measure the number of countries that contributed to the scientific field by means of scientific journals.

-*Stabilization countries:* When there is a change in the countries contributing to a scientific field, this means that there are more countries involved. This is especially the case as the top 10 of countries of a specific field is changing since these countries contribute the most to the field. When the top 10 is stable, this means that the same countries are contributing each year which has a less global character. This indicator will be measured by comparing the top 10 of countries for different years and will result in the percentage of same countries in these years.

-*Percentage internationally co authored:* When this percentage is rising, the globalization is also rising since there is more collaboration between different countries. This will be measured by the percentage of scientific journals in a field that have two or more authors from a different internationality per year.

4- Growth of knowledge production

-*Articles per year:* When more articles are written each year, this means a rise in produced knowledge. This indicator shows the number of scientific articles in a field per year.

5- Knowledge accumulation

-*Cited half life and citing half life:* Points to the median age of the articles in a journal that were cited by other journals in a year (in this research the year 2009). So 50% of the cited articles of a scientific field were cited more recently than the cited half life. A cited half life of 5 years means that 50% of the cited articles for that field were publishes between 2005 and 2009. The citing half life represents the median age of the articles that were cited by the articles published in the journal in a year (also 2009). A low cited and citing half life means more knowledge accumulation since more knowledge is based on earlier work.

-*Stabilization cited journals*: Represents the top 50 journals which are cited by a scientific field. When the journals are stable over the years this means that knowledge is derived and builds on similar sources. When the top 50 is less consistent, this means that knowledge is derived from different sources, which can also mean from sources from different fields. Fewer sources mean a more common view of scientific progress and thus more knowledge accumulation. This will also be measured by means of comparing the top 50 of cited journals for several years and measure the similarity in percentages.

-*Times cited*: In case papers form a scientific field are cited frequently, this means that the knowledge accumulates more on earlier work than in case papers are less cited. This will be measured by means of the average number of citation per paper per year for each field.

6- Divergence topics

-*Stabilization keywords:* The divergence of topics can be measured by means of keywords used by journals. When the same keywords are used over the years this means there is a convergence of the topics. In case the keywords change a lot more, this means that there is a high diversity of topics. The stability of the keywords is measured by means of the stability of the top 50 used keywords in articles for each field in the same way as the indicators *stabilization countries* and *stabilization cited journals* are measured. A high stability means a high convergence and a low stability means a high divergence.

Since the differences between dimensions are relative to other fields, it is not possible to assign measurement scores for each indicator a priori. However, to compare fields and their dimensions, scores are necessary. Therefore scores will be assigned during analyzing the results. A five point ordinal scale will be set up for each dimension. The average result of each field will be used to set up the five point distribution. A score of 3 will be given to fields that are near the average result, a score of 1 will be given to results that are much lower than the average and a score of 5 is attached to fields that have a much higher result. A score of 2 or 4 are going to fields with results that fall between these scores (2 a little lower than average and 4 a little higher). When a dimension has several indictors, the average of these indicator scores will be the score for tat dimension. This way, each scientific field will have a score attached to each dimension, so that the results can be compared more consistently. Note that these scores are not quantitative scores but merely an aid in comparing dimensions of different fields.

When all scores are attached to each dimension for each field, the scores of each dimension can be compared. Dimensions are highly present in a field when the score is far above average (for example a score of 4,3) and they have a low presence when they score much lower than average (for example a score of 2).

These scores will aid in analyzing the results qualitatively. The expected correlation among dimensions, as assumed by each theory, can be studied. For example, hard sciences are expected to have a higher score for both knowledge accumulation and globalization than soft sciences. By comparing the scores of these two dimensions for each field, it can be analyzed whether this distinction is really present. Researching and analyzing the expected correlation among dimensions will be done for each theory.

The results will be analyzed qualitatively, because this research focuses on understanding why the dimensions and the correlation among these dimensions are present and there are no quantitative scores available. Furthermore, the sample of 21 scientific fields is too small to measure quantitative influences while it is enough for qualitative analysis. The next chapter will display the results of the research.

Results

In this section the results will be presented by means of tables and graphs. The results will only be described and not interpreted since that will be done in the conclusion section. The six dimensions and their indicators will be presented and scores will be attached in order to be able to analyze the data. How the scores are attached for each indicator can be found in exhibit A.

1- Collaboration between scientists

Only the indicator *average number of authors per paper* is used to research this dimension. There are two ways to look at the number of authors per paper. The first one is by looking at the absolute average of the number of authors per paper and the second one is to look at the change of the average number between 1995 and 2009. Both will indicate how the collaboration between scientists of a scientific field compares to other fields. Table 5 represents both ways.

First of all can be seen that the average number of authors has grown between 1995 – 2009 with an average of 1 person per paper (a growth of 55,6%). The total score of astronomics, climate research, medicine and diseases and psychology are the highest. In these fields, the collaboration between scientists is the highest. The fields of energy and organic chemistry show a very low score for collaboration between scientists.

Table 5: Number of authors per article and the change between 1995 - 2009

Field	Number of authors 2009	Score	Change % 1995-2009	Score	Total score
Astronomics	4,48	4	87,10%	5	4,5
Biotechnology	2,25	2	37,91%	2	2
Climate research	4,32	4	187,97%	5	4,5
Computer science	3,65	3	109,60%	5	4
Economics	2,02	1	41,53%	3	2
Energy	1,75	1	11,92%	1	1
Genomics	3,19	3	5,27%	1	2
Geo science	2,76	2	32,74%	2	2
Geography (physical)	3,58	3	105,17%	5	4
High Energy Physics	2,39	2	9,20%	1	1,5
Immunology	1,89	1	23,46%	2	1,5
Information science	1,81	1	39,48%	2	1,5
Innovation studies	2,04	1	30,33%	2	1,5
Medicine diseases	5,58	5	64,85%	4	4,5
Nanotechnology	2,39	2	105,19%	5	3,5
Neuroscience	3,52	3	66,22%	4	3,5
Organic chemistry	1,62	1	18,38%	1	1
Pharmacology	2,04	1	33,42%	2	1,5
Psychology	3,90	4	82,47%	5	4,5
Virology	2,94	2	38,09%	2	2
Biotchemistry	4,27	4	66,26%	4	4
Average	2,97		55,61%		

2- Presence of science, industry and government

The results of the percentage of the presence of science, industry and government within scientific fields are shown in exhibit B. It can be seen that overall the percentage of contribution of universities are slightly growing, the participation of the public sector started to grow from 1995 until 2000, but stabilized afterwards and the participation of the industry is slowly declining. This is visually represented in figure 1. Overall, the most knowledge is created in universities (over 60%) while the public sector and certainly the industry contribute much less. The scores can be measured for 2009 and for the change between 1995 and 2009. The average scores for both of these will be used for the score of each field.

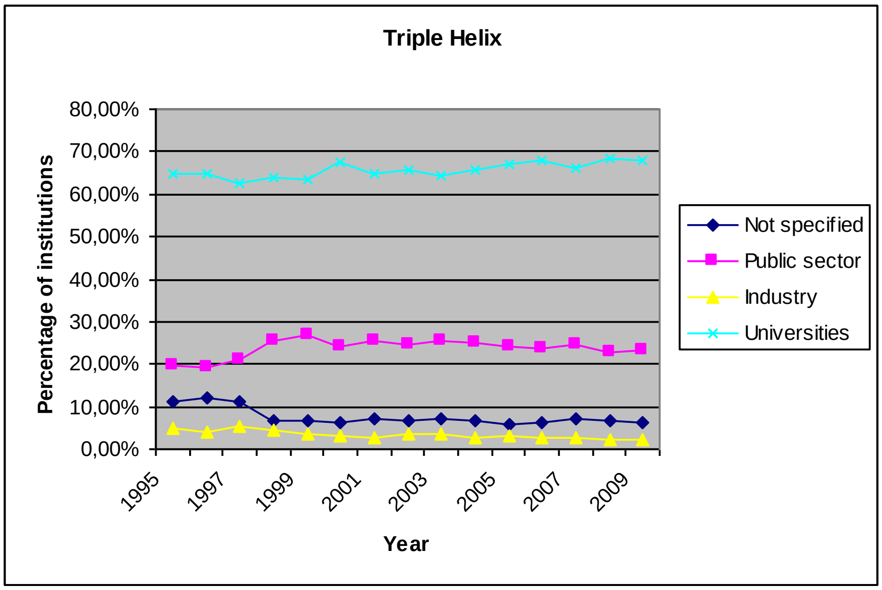

Figure 1: Average participation of public sector, industry and universities of all sampled scientific fields

Science / universities

In 2009, the following scientific fields are mainly driven by universities, relatively compared to other scientific fields: computer science, economics and information sciences. Universities played a smaller role in 2009 in the following fields: geoscience, climate research, genomics and astronomics. The participations of universities have not changed much over the years. Only in energy, computer science, nanotechnology and psychology the participation of universities have grown significantly, whereas in genomics, immunology, climate research and physical geography this participation even declined. When considering both the year 2009 and the change from 1995-2009 we see that universities are well presented in computer science and psychology and are very low presented in climate research, genomics and immunology.

Government / public sector

In 2009, the following scientific fields were mainly driven the government, relatively compared to other scientific fields: astronomics, genomics, climate research, geoscience and immunology. The participation of the government has grown the most in the field of neuroscience and organic chemistry. The participation of the government is very low in a lot of fields in 2009: computer science, economics, geography (physical), information science, innovation studies, organic chemistry, pharmacology and psychology. The participation has decreased in the fields of computer science, innovation studies, nanotechnology and psychology. In the case of psychology the participation even decreased with almost 36%. In total, the participation of the government is high for astronomics, climate research, geoscience and immunology. It is low for computer science, innovation studies and psychology.

Industry
The participation of the industry is very low compared to the participation of universities and the public sector, and it is even slowly declining. In 2009, the participation is certainly low in the field of economics (almost no participation), physical geography, high energy physics, innovation studies, neurology and psychology. The fields in which participation of the industry has declined the most are nanotechnology and neuroscience. The fields with a relatively high participation of the industry in 2009 are biotechnology, energy, genomics and pharmacology. But these numbers do not exceed 7% in 2009. However, the participation of the industry in genomics has grown with more than 130% to 3,3% in 2009. Other rises of participation of the industry can be seen in astronomics, biochemistry, biotechnology and organic chemistry (all more than 40%). In total the following fields have the most participation of the industry: biotechnology, climate research, genomics and astronomics. A low participation is for: economics, high energy physics, innovation studies, neuroscience and psychology.

3- Globalization

Globalization is researched by means of three indicators, namely *countries per year*, *stabilization countries* and *percentage internationally co authored*.

-Countries per year
The results of this indicator can be seen in table 6. This indicator is formed by three different sets of data. The first set of data is the data about the number of countries in 2009. The second set of data is about the total number of different countries from 1995 – 2009. The third data set is the change of the number of countries between 1995 and 2009. The average number of countries of all scientific fields in the sample have grown with 54%, the average number of countries per field was 41,8 in 2009. In 2009, the countries with articles from more than 50 countries were astronomics, geosciences, nanotechnology, organic chemistry and virology. From these fields, especially the number of countries from nanotechnology have grown, namely with 600%. Other fields which have more than doubled the number of countries compared to 1995 are climate research, energy, physical geography and virology. Genomics is the only field which has a decreased number of countries compared to 1995. Fields with less than 30 countries in 2009 are economics, genomics, immunology, neuroscience, pharmacology and biochemistry. The fields with most countries over 15 years are astronomics, geosciences and virology (more than 90 different countries). Combining the three forms of data the following scientific field score high for this indicator: astronomics, energy, nanotechnology, neuroscience and virology. Fields that score low are: economics, genomics, immunology, neuroscience and biochemistry.

Table 6: Number of countries

Number of countries	**2009**	**Score**	**Total**	**Score**	**Change % 1995-2009**	**Score**	**Total score**
Astronomics	67	5	93	5	28,85%	2	4,0
Biotechnology	45	3	70	3	36,36%	3	3,0
Climate research	39	2	84	4	143,75%	5	3,7
Computer science	33	2	66	3	26,92%	2	2,3
Economics	25	1	39	1	25,00%	2	1,3
Energy	57	4	75	3	137,50%	5	4,0
Genomics	27	1	73	3	-10,00%	1	1,7
Geo science	60	4	134	5	11,11%	2	3,7
Geography (physical)	39	2	77	3	105,26%	5	3,3
High Energy Physics	47	3	79	3	11,90%	2	2,7
Immunology	20	1	40	1	17,65%	2	1,3
Information science	41	3	72	3	64,00%	4	3,3
Innovation studies	32	2	53	2	77,78%	4	2,7
Medicine diseases	31	2	66	3	40,91%	3	2,7
Nanotechnology	56	4	82	4	600,00%	5	4,3
Neuroscience	29	1	48	1	38,10%	3	1,7
Organic chemistry	58	4	97	5	31,82%	3	4,0
Pharmacology	27	1	50	1	92,86%	5	2,3
Psychology	33	2	64	2	32,00%	3	2,3
Virology	70	5	119	5	112,12%	5	5,0
Biochemistry	28	1	51	2	27,27%	2	1,7
Average	41,8		74,05		53,96%		

-Stabilization of countries

For this indicator the ten countries that produced the most scientific papers for each scientific fields in 1995, 2002 and 2009 are compared. This way the turbulence of the top 10 can be compared for each scientific field. The results can be seen in table 7. The countries were the top 10 remained the same the most are astronomics and geosciences. In both cases more than 80% of the countries in the top 10 were also present in the top 10 in the years before. On the contrary, in the fields of genomics, information science, innovation studies and nanotechnology the top 10 are not steady. All times, not more than 60% countries are similar to the previous years.

Table 7: the distribution of the top 10 countries of each field. A comparison of 2002 with 1995 and of 2009 with 1995 and 2002.

Distribution countries	2002		2009				Average	Score
Astronomics	Similar 1995	100,00%	Similar 1995	90,00%	Similar 2002	90,00%	93,33%	5
Biotechnology	Similar 1995	90,00%	Similar 1995	80,00%	Similar 2002	70,00%	80,00%	4
Climate research	Similar 1995	60,00%	Similar 1995	70,00%	Similar 2002	70,00%	66,67%	2
Computer science	Similar 1995	60,00%	Similar 1995	60,00%	Similar 2002	90,00%	70,00%	3
Economics	Similar 1995	60,00%	Similar 1995	80,00%	Similar 2002	60,00%	66,67%	2
Energy	Similar 1995	80,00%	Similar 1995	70,00%	Similar 2002	80,00%	76,67%	4
Genomics	Similar 1995	70,00%	Similar 1995	50,00%	Similar 2002	60,00%	60,00%	1
Geo science	Similar 1995	80,00%	Similar 1995	90,00%	Similar 2002	80,00%	83,33%	5
Geography (physical)	Similar 1995	60,00%	Similar 1995	70,00%	Similar 2002	80,00%	70,00%	3
High Energy Physics	Similar 1995	80,00%	Similar 1995	80,00%	Similar 2002	80,00%	80,00%	4

Immunology	Similar 1995	80,00%	Similar 1995	70,00%	Similar 2002	60,00%	70,00%	3
Information science	Similar 1995	60,00%	Similar 1995	60,00%	Similar 2002	40,00%	53,33%	1
Innovation studies	Similar 1995	60,00%	Similar 1995	60,00%	Similar 2002	60,00%	60,00%	1
Medicine diseases	Similar 1995	80,00%	Similar 1995	70,00%	Similar 2002	80,00%	76,67%	4
Nanotechnology	Similar 1995	50,00%*	Similar 1995	40,00%	Similar 2002	90,00%	60,00%	1
Neuroscience	Similar 1995	70,00%	Similar 1995	50,00%	Similar 2002	80,00%	66,67%	2
Organic chemistry	Similar 1995	70,00%	Similar 1995	70,00%	Similar 2002	90,00%	76,67%	4
Pharmacology	Similar 1995	80,00%	Similar 1995	60,00%	Similar 2002	70,00%	70,00%	3
Psychology	Similar 1995	70,00%	Similar 1995	80,00%	Similar 2002	60,00%	70,00%	3
Virology	Similar 1995	90,00%	Similar 1995	70,00%	Similar 2002	70,00%	76,67%	4
Biochemistry	Similar 1995	80,00%	Similar 1995	80,00%	Similar 2002	80,00%	80,00%	4
								*Only 8 countries in 1995

-Percentage internationally co authored

For this indicator it is also looked at the percentage of international co-authored articles in 2009 and to the change from 1995 until 2009. The percentage of internationally co authored articles has risen from 1995 to 2009 with more than 75%. The results for all fields can be found in table 8. The fields with a high percentage of international co-authors are astronomics, physical geography and medicine and diseases. The fields that have the highest growth of internationally coauthored articles are climate research, economics, information science, innovation studies and nanotechnology. The fields with a very low percentage in 2009 are biotechnology, energy, information science and organic chemistry. Of these fields, the field of energy has also decreased with more than 11% from 1995-2009. Genomics has also decreased with more than 5%. Both types of data including, the fields with a high score for this indicator are economics and physical geography. The field with a very low score is energy.

Table 8: percentage of international co authored articles.

Scientific field	2009	Score	Change % 1994-2009	Score	Total Score
Astronomics	52,67%	5	65,22%	3	4
Biotechnology	17,98%	1	60,57%	3	2
Climate research	31,68%	3	216,79%	5	4
Computer science	29,56%	3	23,71%	2	2,5
Economics	41,25%	4	168,13%	5	4,5
Energy	15,57%	1	-11,35%	1	1
Genomics	27,10%	3	-5,26%	1	2
Geo science	39,33%	4	53,65%	3	3,5
Geography (physical)	55,37%	5	111,42%	4	4,5
High Energy Physics	39,77%	4	16,54%	2	3
Immunology	22,22%	2	48,15%	2	2
Information science	17,25%	1	377,35%	5	3
Innovation studies	32,73%	3	292,73%	5	4
Medicine diseases	47,02%	5	48,71%	2	3,5
Nanotechnology	24,29%	2	483,02%	5	3,5
Neuroscience	28,11%	3	101,89%	4	3,5
Organic chemistry	12,76%	1	62,79%	3	2
Pharmacology	18,57%	2	88,37%	3	2,5
Psychology	37,82%	4	129,15%	4	4
Virology	27,82%	3	73,21%	3	3
Biochemistry	32,23%	3	57,04%	3	3
Average	31,01%		75,09%		

-Total score globalization

When calculating a score for each scientific field for this dimension, the average of the total score of all indicators is taken. The result can be seen in table 9. The fields that score high are astronomics, geosciences and virology. Fields that score low are economics, genomics, information science, innovation studies and neuroscience.

Table 9: Total score for the dimension Globailzation, based on all three indicators

Field	Number of countries	Distribution countries	Percentage international co-authored	Total
Astronomics	4,00	5,00	5,00	4,67
Biotechnology	3,00	4,00	4,00	3,67
Climate research	3,67	2,00	2,00	2,56
Computer science	2,33	3,00	3,00	2,78
Economics	1,33	2,00	2,00	1,78
Energy	4,00	4,00	4,00	4,00
Genomics	1,67	1,00	1,00	1,22
Geo science	3,67	5,00	5,00	4,56
Geography (physical)	3,33	3,00	3,00	3,11
High Energy Physics	2,67	4,00	4,00	3,56
Immunology	1,33	3,00	3,00	2,44
Information science	3,33	1,00	1,00	1,78
Innovation studies	2,67	1,00	1,00	1,56
Medicine diseases	2,67	4,00	4,00	3,56
Nanotechnology	4,33	1,00	1,00	2,11
Neuroscience	1,67	2,00	2,00	1,89
Organic chemistry	4,00	4,00	4,00	4,00
Pharmacology	2,33	3,00	3,00	2,78
Psychology	2,33	3,00	3,00	2,78
Virology	5,00	4,00	4,00	4,33
Biochemistry	1,67	4,00	4,00	3,22

<u>4 – Growth of knowledge production</u>

The only indicator to research the growth of knowledge is by means of the number of articles per year and the growth from 1995 – 2009. Results are shown in table 10. The fields that have more than 1000 articles published in 2009 are astronomics, geosciences, nanotechnology, organic chemistry and virology. From these, nanotechnology has grown with 5200% since 1995. Furthermore the fields of energy, physical geography, information science and innovation studies are growing relatively rapid. There are three scientific fields that have declined over the years, namely genomics, neuroscience and biochemistry. In total, the fields with most knowledge creation are energy, geosciences, organic chemistry and virology. The least knowledge creation is in the fields of economics, genomics, immunology, medicine diseases, neuroscience and biochemistry.

Table 10: Total number of articles per year and the growth from 1995-2009 per scientific field

Field	2009	Score	Change % 1995-2009	Score	Total score
Astronomics	2530	5	22,58%	2	3,5
Biotechnology	367	2	46,80%	3	2,5
Climate research	266	2	77,33%	4	3
Computer science	159	1	40,71%	3	2
Economics	82	1	3,80%	2	1,5
Energy	733	3	395,27%	5	4
Genomics	107	1	-73,38%	1	1
Geo science	1218	5	37,47%	3	4
Geography (physical)	121	1	181,40%	5	3
High Energy Physics	176	1	39,68%	3	2
Immunology	108	1	8,00%	2	1,5
Information science	284	2	238,10%	5	3,5
Innovation studies	110	1	129,17%	5	3
Medicine diseases	154	1	13,24%	2	1,5
Nanotechnology	1272	5	5200,00%	5	5
Neuroscience	217	1	-8,44%	1	1
Organic chemistry	1388	5	47,03%	3	4
Pharmacology	141	1	80,77%	4	2,5
Psychology	156	1	51,46%	3	2
Virology	1251	5	56,96%	3	4
Biochemistry	290	2	-21,62%	1	1,5
Average	530		54,97%		

5- Knowledge accumulation

-Cited half life and citing half life

The cited and citing half life were derived from the journal citation index and is only available for the year 2009. Unfortunately, the numbers were not available for economics and innovation studies. The results are found in table 11. The average of the cited half life is 6,8 and from the citing half life 6,6. Fields with numbers above these have a lower accumulation than numbers below the average. Fields that have both the cited half life and citing half life low are: climate research, immunology, and nanotechnology. The fields that have both indicators above average are: biotechnology, computer science, organic chemistry, psychology and physical geography.

Table 11: Cited half life and citing half life

Field	Cited half life	score	Citing half life	score	Total score
Astronomics	7,2	3	6,5	3	3
Biotechnology	8,2	2	7,9	2	2
Climate research	6	4	5,8	4	4
Computer science	9	2	8,9	2	2
Economics					
Energy	4,9	4	7,4	3	3,5
Genomics	10	1	5,8	4	2,5
Geo science	5,6	4	6,2	3	3,5
Geography (physical)	6,2	3	9,4	1	2

High Energy Physics	3,8	5	7,6	2	3,5
Immunology	5,4	4	3,2	5	4,5
Information science	5	4	7	3	3,5
Innovation studies					
Medicine diseases	6,6	3	5,2	4	3,5
Nanotechnology	3,3	5	5,2	4	4,5
Neuroscience	7	3	6,2	3	3
Organic chemistry	9,6	1	7,4	3	2
Pharmacology	6,6	3	6,1	3	3
Psychology	8,9	2	7,6	2	2
Virology	7,1	3	7	3	3
Biotchemistry	8,7	2	4,7	4	3
Average	6,794737		6,584211		

-Stabilization cited journals

Similarly to the stabilization of countries and keywords, the stabilization of the journals that are cited in scientific fields is researched. This is done with the top 50 of cited journals for each field and can be seen in table 12. The fields which have the most stability when it comes to the same cited journals are astronomics, organic chemistry, virology and biochemistry. The fields with the least stability throughout the years are information science, nanotechnology and pharmacology.

Table 12: stability of cited journals

Cited journals	**2002**		**2009**				**Average**	**Score**
Astronomics	Similar 1995	82,00%	Similar 1995	70,00%	Similar 2002	80,00%	77,33%	5
Biotechnology	Similar 1995	86,00%	Similar 1995	60,00%	Similar 2002	70,00%	72,00%	4
Climate research	Similar 1995	64,00%	Similar 1995	54,00%	Similar 2002	72,00%	63,33%	3
Computer science	Similar 1995	48,00%	Similar 1995	42,00%	Similar 2002	68,00%	52,67%	2
Economics	Similar 1995	57,00%	Similar 1995	54,00%	Similar 2002	74,00%	61,67%	3
Energy	Similar 1995	60,00%	Similar 1995	50,00%	Similar 2002	60,00%	56,67%	2
Genomics	Similar 1995	78,00%	Similar 1995	54,00%	Similar 2002	60,00%	64,00%	3
Geo science	Similar 1995	76,00%	Similar 1995	54,00%	Similar 2002	68,00%	66,00%	4
Geography (physical)	Similar 1995	50,00%	Similar 1995	42,00%	Similar 2002	70,00%	66,00%	2
High Energy Physics	Similar 1995	60,00%	Similar 1995	66,00%	Similar 2002	72,00%	66,00%	4
Immunology	Similar 1995	74,00%	Similar 1995	60,00%	Similar 2002	68,00%	67,33%	4
Information science	Similar 1995	30,00%	Similar 1995	42,00%	Similar 2002	46,00%	39,33%	1
Innovation studies	Similar 1995	44,00%	Similar 1995	54,00%	Similar 2002	62,00%	53,33%	2
Medicine diseases	Similar 1995	66,00%	Similar 1995	54,00%	Similar 2002	72,00%	64,00%	3
Nanotechnology	Similar 1995	38,00%	Similar 1995	32,00%	Similar 2002	62,00%	44,00%	1
Neuroscience	Similar 1995	72,00%	Similar 1995	58,00%	Similar 2002	78,00%	69,33%	4
Organic chemistry	Similar 1995	84,00%	Similar 1995	70,00%	Similar 2002	80,00%	78,00%	5
Pharmacology	Similar 1995	52,00%	Similar 1995	46,00%	Similar 2002	52,00%	50,00%	1
Psychology	Similar 1995	68,00%	Similar 1995	64,00%	Similar 2002	72,00%	68,00%	4
Virology	Similar 1995	76,00%	Similar 1995	68,00%	Similar 2002	82,00%	75,33%	5
Biochemistry	Similar 1995	76,00%	Similar 1995	68,00%	Similar 2002	78,00%	74,00%	5

-Times cited

Table 13 shows the results of the times that articles of each scientific field are cited on average. This indicator can also be measured for the number for 2009 and the change percentage between 1995 and 2009. The fields that are a lot more cited than the average (49 times) in 2009 are astronomics, physical geography, pharmacology and biochemistry. Fields that have a high growing number of times cited are astronomics, information science, innovation studies, nanotechnology and pharmacology. Fields that had a very low number of citations in 2009 are energy, geosciences, information sciences and nanotechnology. Immunology is the only field which had its times cited decreased. In total, fields that score high for this indicator are physical geography and innovation studies. A field that score very low is energy.

Table 13: times cited per article in each scientific field

Field	**2009**	**Score**	**Change % 1994-2009**	**Score**	**Total score**
Astronomics	64,16561	5	70,94%	5	5
Biotechnology	38,42507	2	35,11%	3	2,5
Climate research	44,57895	2	50,84%	4	3
Computer science	36,38365	2	43,45%	4	3
Economics	36	2	41,70%	4	3
Energy	30,09413	1	19,89%	2	1,5
Genomics	40,27103	2	10,02%	2	2
Geo science	21,6601	1	26,72%	3	2
Geography (physical)	64,35537	5	53,65%	4	4,5
High Energy Physics	57,52273	4	60,46%	4	4
Immunology	52,09259	4	-6,89%	1	2,5
Information science	33,22183	1	86,29%	5	3
Innovation studies	59,41818	4	67,77%	5	4,5
Medicine diseases	37,22727	2	16,98%	2	2
Nanotechnology	31,29874	1	115,23%	5	3
Neuroscience	58,14286	4	20,76%	2	3
Organic chemistry	46,70389	3	19,91%	2	2,5
Pharmacology	106,8794	5	72,64%	5	5
Psychology	45,44872	3	18,15%	2	2,5
Virology	49,58193	3	5,11%	2	2,5
Biochemistry	70,96897	5	20,90%	2	3,5
Average	48,78291		36,28%		

- Total score knowledge accumulation

For the score for the dimension for each scientific field, the average of all indicators is used. The results are in table 14. The fields with a relatively high knowledge accumulation are astronomics, high energy physics, immunology and biochemistry. The fields with a relatively low knowledge accumulation are computer science, energy, genomics, geo science and information science.

Table 14: Scores for each indicator and the total score of the dimension knowledge accumulation

Field	Cited/citing half life	Cited journal	Times cited	Total
Astronomics	3	5	5	4,3
Biotechnology	2	4	2,5	2,8
Climate research	4	3	3	3,3
Computer science	2	2	3	2,3
Economics	missing	3	3	3,0
Energy	3,5	2	1,5	2,3
Genomics	2,5	3	2	2,5

Geo science	3,5	2	2	2,5
Geography (physical)	2	4	4,5	3,5
High Energy Physics	3,5	4	4	3,8
Immunology	4,5	4	2,5	3,7
Information science	3,5	1	3	2,5
Innovation studies	missing	2	4,5	3,3
Medicine diseases	3,5	3	2	2,8
Nanotechnology	4,5	1	3	2,8
Neuroscience	3	4	3	3,3
Organic chemistry	2	5	2,5	3,2
Pharmacology	3	1	5	3,0
Psychology	2	4	2,5	2,8
Virology	3	5	2,5	3,5
Biochemistry	3	5	3,5	3,8

6 – Divergence topics

This dimension is measured by means of the stability of keywords. Table 15 provides the data for the stabilization of keywords over the years in a similar manner as the stabilization of countries (table 6). There are three fields that are very consistent in used keywords, being astronomics, organic chemistry and virology. The fields with more variety in the keywords are economics, nanotechnology and pharmacology, which use less than 30% of the same keywords as preceding years.

Table 15: the distribution of the top 50 keywords of each field. A comparison of 2002 with 1995 and of 2009 with 1995 and 2002.

Keywords	**2002**		**2009**				Average	Score
Astronomics	Similar 1995	60,00%	Similar 1995	60,00%	Similar 2002	72,00%	64,00%	5
Biotechnology	Similar 1995	60,00%	Similar 1995	52,00%	Similar 2002	66,00%	59,33%	4
Climate research	Similar 1995	42,00%	Similar 1995	32,00%	Similar 2002	58,00%	44,00%	3
Computer science	Similar 1995	50,00%	Similar 1995	46,00%	Similar 2002	62,00%	52,67%	4
Economics	Similar 1995	22,00%	Similar 1995	14,00%	Similar 2002	22,00%	19,33%	1
Energy	Similar 1995	46,00%	Similar 1995	46,00%	Similar 2002	64,00%	52,00%	4
Genomics	Similar 1995	60,00%	Similar 1995	36,00%	Similar 2002	50,00%	48,67%	3
Geo science	Similar 1995	58,00%	Similar 1995	50,00%	Similar 2002	70,00%	59,33%	4
Geography (physical)	Similar 1995	38,00%	Similar 1995	34,00%	Similar 2002	56,00%	42,67%	3
High Energy Physics	Similar 1995	28,00%	Similar 1995	34,00%	Similar 2002	52,00%	38,00%	2
Immunology	Similar 1995	44,00%	Similar 1995	36,00%	Similar 2002	48,00%	42,67%	3
Information science	Similar 1995	36,00%	Similar 1995	36,00%	Similar 2002	44,00%	38,67%	2
Innovation studies	Similar 1995	34,00%	Similar 1995	28,00%	Similar 2002	50,00%	37,33%	2
Medicine diseases	Similar 1995	32,00%	Similar 1995	26,00%	Similar 2002	48,00%	35,33%	2
Nanotechnology	Similar 1995	16,00%*	Similar 1995	10,00%	Similar 2002	54,00%	26,67%	1
Neuroscience	Similar 1995	46,00%	Similar 1995	38,00%	Similar 2002	56,00%	46,67%	3
Organic chemistry	Similar 1995	74,00%	Similar 1995	66,00%	Similar 2002	74,00%	71,33%	5
Pharmacology	Similar 1995	30,00%	Similar 1995	26,00%	Similar 2002	28,00%	28,00%	1
Psychology	Similar 1995	38,00%	Similar 1995	36,00%	Similar 2002	56,00%	43,33%	3
Virology	Similar 1995	64,00%	Similar 1995	64,00%	Similar 2002	84,00%	70,67%	5
Biochemistry	Similar 1995	54,00%	Similar 1995	48,00%	Similar 2002	58,00%	53,33%	4
								* Only 23 keywords in 1995

The data and results will be analyzed in the next section in order to come up with a conclusion of which dimensions and which correlation among dimensions are most useful for distinguishing scientific fields.

Analysis and Conclusion

In this section the results will be interpreted and analyzed to answer the research question:

Which dimensions and which correlation among these dimensions are most useful for distinguishing scientific fields?

The first part of the research question is provided on basis of a literature section and answered in the theory section, being: collaboration between scientists, presence of science, industry and government, globalization, growth of knowledge production, knowledge accumulation and divergence topics. For the second part of the research question, the expectations for each theory are researched by analyzing whether the correlation between the dimensions as proposed by the theories can also be found in the empirical data. Table 16 shows a summary of all dimensions and their scores for each scientific field.

Table 16: Summary of the scores for each dimension and scientific field

Scientific field	Collaboration between scientists	Collaboration between science, industry and government			Globalization	Growth of knowledge production	Knowledge accumulation	Divergence topics
		Public sector	Industry	Universities				
Astronomics	4,5	4,5	2,5	2,5	4,7	3,5	4,3	5,0
Biotechnology	2,0	4,0	3,0	2,5	3,7	2,5	2,8	4,0
Climate research	4,5	2,0	5,0	2,5	2,6	3,0	3,3	3,0
Computer science	4,0	4,5	4,5	1,5	2,8	2,0	2,3	4,0
Economics	2,0	1,0	2,0	5,0	1,8	1,5	3,0	1,0
Energy	1,0	2,5	1,0	3,5	4,0	4,0	2,3	4,0
Genomics	2,0	2,0	3,5	4,0	1,2	1,0	2,5	3,0
Geo science	2,0	4,0	5,0	1,5	4,6	4,0	2,5	4,0
Geography (physical)	4,0	4,5	4,0	2,5	3,1	3,0	3,5	3,0
High Energy Physics	1,5	1,5	4,0	2,0	3,6	2,0	3,8	2,0
Immunology	1,5	2,5	1,0	3,5	2,4	1,5	3,7	3,0
Information science	1,5	4,5	3,5	1,5	1,8	3,5	2,5	2,0
Innovation studies	1,5	1,5	2,5	3,5	1,6	3,0	3,3	2,0
Medicine diseases	4,5	1,0	1,5	3,5	3,6	1,5	2,8	2,0
Nanotechnology	3,5	2,5	3,5	3,0	2,1	5,0	2,8	1,0
Neuroscience	3,5	2,0	2,0	4,0	1,9	1,0	3,3	3,0
Organic chemistry	1,0	3,5	1,5	3,0	4,0	4,0	3,2	5,0
Pharmacology	1,5	3,0	3,5	3,0	2,8	2,5	3,0	1,0
Psychology	4,5	2,0	4,0	3,0	2,8	2,0	2,8	3,0
Virology	2,0	1,0	1,5	4,5	4,3	4,0	3,5	5,0
Biochemistry	4,0	4,0	4,0	3,0	3,2	1,5	3,8	4,0

In order to compare scientific fields and be able to research the correlation among dimensions, scores are attached to indicate whether fields have an average, above average or below average score for each dimension.

Following are the analyses based on the results, in which the data is applied to all the theories from the theoretical section. The end of this chapter will provide policy recommendations based on the data and analyses.

Mode 1/ mode 2 knowledge creation (*gibbons et al., 1994*)

According to the theory an expectation has been made regarding the following correlation between the dimensions: *Mode 2 sciences have more collaboration between scientists, have a higher presence of the government and industry and have a lower knowledge accumulation than mode 1 sciences.* With the results as shown in table 15, the following fields were able to be categorized as either a mode 1 or mode 2 science;

Mode 2: Computer science, geosciences, geography and psychology.
Mode 1: Economics, energy, high energy physics, innovation studies, neuroscience, organic chemistry, immunology and virology.

This means that from the 21 scientific fields, 12 fields could be categorized. The other 9 fields did not have the right correlations in order to be classified. From the mode 2 sciences, only the scientific field of computer sciences did really stand out as a mode 2 science. This means the field has a high collaboration between scientists, a high participation of the government and the industry, and a low knowledge accumulation. The fields of geosciences, geography and psychology did only have three out of four dimensions matching the correlation criteria for mode 2 sciences and can thus not totally be classified as such. Furthermore, the field of psychology is not sees as a mode 2 science, but more as an mode 1 science (Heimeriks et al., 2008).

Mode 1 sciences have the same, but opposite correlation, meaning a collaboration of scientists, a lower participation of the government and industry, and a higher knowledge accumulation. From the results of mode 1 sciences, only immunology and virology have all four dimensions correlated as expected. The other fields have one dimension which is either too high, too low or too average. From these eight mode 1 science fields, the fields of economics, energy and innovation studies were expected to have more the characteristics of mode 2 sciences, because they are more application oriented and cover several fields.

In total, there were eight scientific fields characterized as either mode 1 or mode 2 sciences which were also expected. However, only three fields did really match the expected correlation among dimensions.

Triple Helix *(Etzkowitz and Leydesdorf 1997)*

The following correlation among dimensions is proposed in the triple helix theory: *Scientific fields where the presence of government and industry are relatively high are less global.* The opposite correlation is that fields with a low presence of the government and industry should see a higher globalization. The results from table 15 show this correlation in the following scientific fields:

Fields with a high participation of the government and industry and a low globalization: computer sciences and information sciences.

Fields with a low participation of the government and industry and a high globalization: energy, medicine diseases and virology.

Only five out of 21 scientific fields show the expected correlation. This is a low number, meaning that this correlation can hardly be found with the sampled data.

Pasteur's quadrant *(Stokes, 1997)*

This theory expects the following possible distinction between scientific fields, based on the relevant dimensions: *It is possible to make a relevant distinction between fields with both a lot of industry presence AND a high knowledge accumulation(Pasteur), fields with only a high presence of industry (Edison), fields with only a high knowledge accumulation (Bohr) and fields with both very low new knowledge creation and new applications.* The results are shown in table 17, in which the fields that can be categorized are related to the quadrant they belong to according to the data.

Table 17: scientific fields categorized for the theory of Stokes (1997)

	No new applications	New applications
No new knowledge	Energy	Edison's quadrant: Computer science Geo science Psychology
New knowledge	Bohr's quadrant: Astronomics Immunology Organic chemistry Virology	Pasteur's quadrant: Geography (physical) High Energy Physics Biochemistry Climate research

Twelve of the 21 scientific fields can be categorized based on the dimensions relevant for the theory of Pasteur's quadrant. The fields that could not be categorized had most of the times vey average scores compared to other fields so they could not fit in a particular quadrant. The results are not always convincing. It is for instance remarkable that psychology falls in Edison's quadrant, since psychology is a scientific field in which a lot of statistical research is done. It is not expected that this research always only leads to new applications and little new knowledge. However, this distinction of scientific fields seems more relevant than the theories here before since more scientific fields could be categorized.

Search regimes *(Bonaccorsi, 2008)*

The following correlation regarding this theory is expected: *New leading sciences have a lot of collaboration between scientists, a high diversity of topics and a high growth.* There is only one scientific field in which this correlation is found among these dimensions, namely astronomics. This field have a high collaboration between scientists, a high diversity and a high growth. There are other fields which have two of the dimensions interrelated, but they miss the presence of a third dimension, namely computer science, energy, geosciences, nanotechnology, organic chemistry, virology and biochemistry. There is not one dimension that is not present in these seven fields, the dimensions missing are varying. But in most cases (four out of seven) the dimension *collaboration between scientists* is missing, which have a low score compared to other fields.

Furthermore the results of these eight fields are not relevant since only computer sciences, energy and nanotechnology can be seen as a new leading science. The other fields are older sciences that exist for a long time already and thus cannot be seen as new sciences. This means that the relevance of the correlation between dimensions as expected by this theory is very low; only one out of 21 scientific fields can rightfully be categorized as new leading science.

<u>Intellectual and social organization of sciences theory *(Whitley, 2000)*</u>

According to this theory the following correlation between dimensions can distinct scientific fields: *fields can be distinguished between fields that have: high collaboration between scientists, high knowledge accumulation and a low diversity of topics and fields that have a low collaboration between scientists, low knowledge accumulation and a high diversity of topics.* In the results there are no scientific fields that have a high collaboration between scientists, high knowledge accumulation and a low diversity of topics. From the other category four scientific fields can be classified: biotechnology, energy, geosciences and organic chemistry. This is a very low amount of possible classifications and one category does not even exist according to the sampled data. This means that this theory is certainly not grounded by empirical data.

<u>Hard/soft sciences</u>

The last distinction between scientific fields is that of hard and soft sciences. The following expectation regarding correlated dimensions for this theory is: *hard sciences have both more knowledge accumulation and are more global than soft sciences.* This correlation is found in the following scientific fields:

Hard sciences: astronomics, geography (physical), high energy physics, organic chemistry, virology and biochemistry.
Soft sciences: computer science, economics, genomics, information science, nanotechnology and psychology.

Twelve from the 21 scientific fields could be classified as either hard or soft sciences, based on the correlation between knowledge accumulation and globalization. This is the highest result of all researched theories. Furthermore, the results also show a reliable and relevant classification. Only genomics and nanotechnology have more the characteristics of hard sciences than soft sciences. This means that ten out of 21 scientific fields show the correlation between the dimensions knowledge accumulation and globalization in an expected manner, making this a relevant correlation for distinguishing hard and soft sciences.

<u>**Conclusion**</u>

The aim of this research was to find out which correlation among dimensions, as proposed by theories about knowledge development and differences between scientific fields, could also be found in empirical data and are thus most useful for field differentiation. The theories all claim different dimensions and other correlations that cause the distinction between scientific fields. Some theories, like the mode1 / mode 2 theory from Gibbons et al. (1994), the search regimes theory from Bonaccorsi (2008), the triple helix theory (Etzkowitz and Leydesdorf, 1997) and the Intellectual and social organization of sciences theory (Whitley, 2000) have more than two dimensions that interrelate, while other theories like Pasteur's quadrant theory (Stokes, 1997) and the theory of differences between hard and soft sciences claim only two correlations. In the results and analyses can be seen that the theories that claim a correlation between only two dimensions are more grounded in data than the theories with several correlations. In table 18 the number of fields that have been found with a relevant correlation are presented, combined with the number of claimed correlations of each theory.

Table 18: The number of fields found with the correlation as claimed by theories and the number of orrelations they claimed

Theory	Number of fields with relevant correlations of dimensions found in the data (from the 21 possible scientific fields).	Number of correlations between dimensions claimed by each theory.
mode1 / mode 2 sciences (Gibbons et al., 1994)	8	4
Triple Helix theory (Etzkowitz and Leydesdorf, 1997)	5	3
Pasteur's quadrant theory (Stokes, 1997)	12	2
Search regimes theory (Bonaccorsi, 2008)	1	3
Intellectual and social organization of sciences theory (Whitley, 2000)	4	3
Hard / soft sciences	10	2

The theories that claim a lot of correlations in fact have the least number of scientific fields in which this correlation is actually present. Of these, only the mode 1/mode 2 knowledge creation theory has a relatively high result of actual scientific fields that can be characterized based on the dimensions of this theory. The triple helix, search regimes and intellectual and social organization of sciences theories have too little results to be grounded. On the other hand, the theory of Pasteur's quadrant and hard and soft sciences have found more results and are thus more grounded in data. However, they are still not proved, since there are also a lot of scientific fields that do not have the correlation among dimensions as assumed in these theories. A notable result is that both theories are less based on the transition that knowledge creation has gone through the last couple of decades (Martin, 2010). The theory of hard and soft sciences is a more traditional view of differences between scientific fields and the theory of Stokes incorporates a fourth quadrant (Pasteur's quadrant) next to the also more traditional other quadrants (Edison and Bohr). From these quadrants, only three scientific fields can be categorized as a scientific field falling in Pasteur's quadrant, the other 11 fields fall in the more traditional quadrants.

It can be concluded, that based on these results and analyses that the modern theories about how knowledge creating is changing and how scientific fields are differentiating, do not take the relevant correlations and dimensions into account. These newer theories presume a correlation between three or four dimensions, but all these correlations are more often not present than present in scientific fields. This means that scholars did not yet succeed in grasping the relevant elements that influence the growing differences between scientific fields (Heimeriks and Vasileiadou, 2008). From the modern theories how scientific fields differ, the correlation among the elements for distinction of mode 1 and mode 2 sciences can be found in the most scientific fields and this distinction is thus the most relevant distinction of the modern theories. The differences between hard and soft sciences and the distinction of the four quadrants (Stokes, 1997) are most grounded in empirical data and are therefore the most relevant for distinguishing scientific fields. This means that in the case of hard and soft sciences, the correlation between knowledge accumulation and globalization are relevant. In case of the theory of Pasteur's quadrant, the correlation between knowledge accumulation and industry participation is relevant. These correlations are thus most useful for distinguishing scientific fields.

Is knowledge creation changing?

The theories that incorporate the transition in knowledge creation have thus not yet managed to grasp the relevant correlation among dimensions that differentiate the fields and how the knowledge creation has changed over the passed two decades. But does the data show that the indicators and thus the way that knowledge is created are actually changing between 1995 and 2009? In other words: can this data ground the assumption that knowledge creation is in transition?

To answer these questions, the data from the indicators is used that present the differences between 1995 and 2009. These results are presented in the table of exhibit C. The data of *cited half life* and *citing half life* are not included since for these indicators only data was used from 2009. In general the results indicate that the knowledge development is changing. The indicators show changes between 1995 and 2009, varying to different degrees among fields. When looking at the average change of all fields per indicator, we see that all indicators are more present in 2009 than in 1995, except for the presence of the industry. This means that on average there are more authors per paper, more articles per year, more articles with international co-authors, more countries in which knowledge is developed, scientific papers are cited more frequently and the government is more involved. The influence of universities has only changed on average by 5,1%, so this indicator has changed the least. The participation of the industry is the only indicator that has declined (by 53%). Furthermore, we can also see turbulence in the used keywords, the cited journals and the countries that are participating the most.

This means that fields are indeed changing the last 15 years, however these results should be compared to the changes from years before 1995 in order to find out whether the knowledge transition as pointed in theories is indeed higher than before the last two decades. However, when linking the indicators to the six dimensions used in this research, we find there is indeed a growing collaboration between scientists, a growing globalization of knowledge development, an increasing growth of knowledge production, a growing knowledge accumulation and a growing diversity of topics. For the dimension of the presence of science, industry and government, we can only see a growing presence of the government and universities (although the latter is a small growth) and a decline in the presence of the industry.

These results indicate that there is turbulence in scientific fields and in knowledge development. However, a pattern cannot be found within this data making it not possible to grasp which dimensions and which correlation among dimensions can be seen in most fields. When more data is used and more specific research into this matter is conducted, it might be possible to find a relevant distinction between fields based on these dimensions and correlations of dimensions.

Policy implications

Modern western countries are striving for a knowledge based economy in order to compete globally. They want to stimulate scientific fields in order to enhance the quality and quantity of knowledge production. Several theories have tried to grasp the elements that cause the growing differences between scientific fields (Heimeriks and Vasileiadou, 2008). These differences cause scientific fields to respond differently to interventions from governments. The theories have influenced policy measurements by governments concerning knowledge development (Martin, 2010).

The analyses presented in this research have implications for the policies concerning improvements for knowledge development since it evaluates several of the theories that governments take into account. The results show that some theories are better suited for policy making because they are more grounded in empirical data.

The theories that are mainly based on the transition of knowledge development in scientific fields in the past two decades are the theories of mode 1 and mode 2 sciences (Gibbons et al., 1994), the triple helix theory (Etzkowitz and Leydesdorf, 1997), the search regimes theory (Bonaccorrsi, 2008) and the Intellectual and social organization of sciences theory (Whitley, 2000). For all these theories little evidence is found in this research, which means that the correlations between the elements as they propose are not reliable enough to be used as frameworks to base policies on. The notion of mode 1 and 2 sciences and the correlation between collaboration of scientists, industry and government participation and knowledge accumulation is closest to distinct scientific fields and incorporating the knowledge transitions.

The more traditional notion of hard and soft sciences is not based on the knowledge transition. However, the correlations between the elements for this distinction are more present in the data, meaning a more reliable distinction between scientific fields. This distinction is based on the correlation between knowledge accumulation and globalization. Governments should thus take a different approach for policy measurements concerning hard and soft sciences. Measurements for hard sciences can be based on more interactions between global operating institutions, which could increase the knowledge accumulation as well. For soft sciences, this is less useful because both knowledge accumulation and globalization are already low.

Finally, the distinction as made in the theory of Pasteur's quadrant (Stokes, 1997) is also found in a large part of the data. This theory is based on the correlation between knowledge accumulation and the participation of the industry. The quadrants of Bohr and Edison are more traditional and Pasteur's quadrant is somewhat based on the knowledge transition of the last two decades, because this quadrant includes scientific fields that have both new knowledge and new applications. The fourth quadrant is less relevant for policy making since there is no new knowledge and application creation in this quadrant, while the aim of policies is to actually create new knowledge and new applications. Policy making while taking this theory into account should be based on the classification of the scientific fields. Fields falling in Bohr's quadrant are more based on creating knowledge so policy could be to enhance the facilitation of basic research. The fields that fall in Edison's quadrant are more based on creating new applications so here policies could be to enhance the collaboration between universities and the industry. In case of Pasteur's quadrant both new knowledge and new applications are created so policy on scientific fields classified in this quadrant should combine the policies of Edison's and Bohr's quadrants.

A consequence of the results of this research is that the transition of knowledge creation can still not be dealt with. Therefore the theories should be more build around empirical data in order to be relevant. The theory of mode1 and mode 2 sciences claim elements and correlations between dimensions that are approved the most by empirical data of all theories that take the knowledge transition into account. With some adjustments this theory seems to be the most promising theory for future policy. Governmental support for improving this theory could thus be beneficial for future knowledge development.

Discussion

In this section the results and conclusion of this research will be discussed in the light of the ongoing debate about growing differences between scientific fields over the last two decades. There are several theories (which are frequently mentioned in this article) that claim correlations between elements which cause the distinction between scientific fields. Since these theories lack proof in forms of empirical data, the debate continuous without claims based on evidence. This research was a first approach to evaluate the different theories by means of scientometric data and thus empirical proof. Since the theories presume correlations between elements, this research has tested whether these correlations can really be found in scientometric data.

The results of this research shed a new light on the discussion about knowledge transition and how this distinguishes scientific fields. The modern theories that entail the transition of knowledge development, being the mode 1 / mode 2 knowledge creation theory by Gibbons et al. (2009), the triple helix theory by Etzkowitz and Leydesdorf (1997), the search regimes theory by Bonaccorsi (2008) and the intellectual and social organization of sciences theory by Whitley (2000), are not confirmed by the scientometric data used in this research. The theories that include more classic assumptions are the differences between hard and soft sciences and Pasteur's quadrant theory (Stokes, 1997) and these theories are more confirmed by the scientometric data. This means that none of the modern theories did yet grasp the precise elements and correlations that distinguish scientific fields in the time that knowledge development is in transition. The debate is already a proof that there is no consensus and with these results the reason for this lack of consensus can be explained; all the modern theories are not right.

A possibility why the right correlations of elements are not yet combined into a theory that is supported by empirical evidence might be that the current theories presume a presence of too many correlations between elements in each field. In practice there are not many scientific fields with so many correlations between the dimensions. Therefore the more traditional and simpler theories are more supported by evidence and these distinctions are more common in practice.

The results of this research are only a starting point for further exploration into this matter and the research can be done more thoroughly and more extensive. This could be done by the following points:

- For this research, 21 scientific fields were used as a sample. Off course, there are many more scientific fields. Using other scientific fields might have lead to different results. Therefore, data from many more scientific fields are needed for more reliable results.

- In this research, for every scientific field one scientific journal was used to represent that whole specific field (a central tendency journal). Although the scientific journals were carefully picked, other scientific journals could have led to different results. For more precise and better results, more scientific journals per field should be used. This would also result in more reliable and complete data.
- The theories tested in this research are derived by means of a literature study. A literature study has the shortcoming that there is always a chance of leaving out certain insights and other theories. However, the theories used are cited and used in multiple scientific papers (Martin, 2010, Heimeriks and Leydesdorff, 2011, Hessels and van Lente, 2008). Still, other theories that presume possible elements for distinctions between scientific fields might exist and they should also by included in this research.
- Another point is the choice of indicators. The indicators for the research can all be found in data of scientific papers. However, there are other indicators that could be very useful for this study. For example patent data could provide more insights in application characteristics of scientific fields. When more indicators are included in the research this will improve the quality of the results as well.
- A last potential shortcoming of this research is the link between the dimensions and the indicators. It could be argued that the limited set of indicators used here, does not fully capture the conceptual scope of all theories. However, the used indicators are believed to give a solid perception of the dimensions they indicate. The indicators used provide a good starting point for measuring the dimensions, but different indicators or more indicators might have given other results. Furthermore, capturing dimensions with indicators is always a tricky process in every scientific research and always goes along with uncertainties.

When these points are performed in future research, the results will become much more reliable and extensive.

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Exhibits

Exhibit A

Measurement scales used for each indicator, based on the average scores of each field

Indicator	Measurement scales and scores					
Triple Helix 2009	UNIV 2009	score	Industry 2009	score	Government 2009	score
	50%-56%	1	0%-0,7%	1	>18%	1
	57%-63%	2	0,8%-1,5%	2	19%-22%	2
	64%-70%	3	1,6%-2,2%	3	23%-26%	3
	71%-76%	4	2,3%-3%	4	27%-30%	4
	77%<	5	3%<	5	31%<	5
Triple Helix 1995-2009	UNIV	score	Industry	score	Government	score
	negative	1	<-90%	1	negative	1
	0%-3%	2	-90 - -59,9%	2	0%-15%	2
	3,1%-6%	3	-60 - -29,9%	3	16%-30%	3
	6,1%-9%	4	-30-0%	4	31%-45%	4
	9,1%<	5	Positive	5	45%<	5
Countries	2009	score	Total	score	change 1995-2009	score
	20-30	1	35-50	1	negative	1
	31-40	2	51-65	2	0%-30%	2
	41-50	3	66-80	3	31%-60%	3
	51-60	4	81-95	4	61%-90%	4
	61<	5	96<	5	91%<	5
Times cited	Number of times	score	Percentage	score		
	20-35	1	negative	1		
	36-45	2	0%-20%	2		
	46-52	3	21%-40%	3		
	52-59	4	41%-60%	4		
	60<	5	61%<	5		
Authors per paper	2009	score	change 1995-2009	score		
	1,5 -- 2,25	1	0-20%	1		
	2,25 -- 3	2	21%-40%	2		
	3 -- 3,75	3	41%-60%	3		
	3,75 -- 4,5	4	61%-80%	4		
	4,5<	5	81%<	5		
International co-authored	2009	score	Change 1995-2009	Score		
	10-17%	1	negative	1		
	18-25%	2	0%-50%	2		
	26-33%	3	51%-100%	3		
	33-40%	4	101%-150%	4		
	41%<	5	151%<	5		
Number of Articles	2009	score	Change 1995-2009	score		
	0-250	1	negative	1		
	251-500	2	0%-30%	2		
	501-750	3	31%-60%	3		
	751-1000	4	61%-90%	4		
	1001<	5	90%<	5		

Stabilization keywords	Percentage	score
	<30%	1
	31%-40%	2
	41%-50%	3
	51%-60%	4
	61%<	5
Cited and citing half life	half life	score
	3-4,5	5
	4,6-6	4
	6-7,5	3
	7,5-9	2
	9<	1
Distribution cited journals	Percentage	score
	>50%	1
	51%-57%	2
	58%-65%	3
	66%-73%	4
	74%<	5
Stabilization countries	Percentage	score
	>60%	1
	61%-68%	2
	69%-75%	3
	76%-82%	4
	83%<	5

Exhibit B

Results for the indicator: Presence of government, industry and universities.

Scientific field	Institution	2009	Score	Change % 1995-2009	Score	Total score
Astronomics	Not specified	7,86%		-57,77%		
	Public sector	32,71%	5	43,93%	4	4,5
	Industry	0,90%	2	-52,69%	3	2,5
	University	58,53%	2	3,12%	3	2,5
Biochemistry	Not specified	3,61%		-69,28%		
	Public sector	28,84%	4	44,06%	4	4
	Industry	1,99%	3	-36,76%	3	3
	University	65,56%	3	0,74%	2	2,5
Biotechnology	Not specified	7,87%		-43,83%		
	Public sector	19,37%	2	14,56%	2	2
	Industry	6,17%	5	42,01%	5	5
	University	66,59%	3	2,86%	2	2,5
Climate research	Not specified	6,09%		-41,11%		
	Public sector	33,33%	5	35,67%	4	4,5
	Industry	2,35%	4	9,03%	5	4,5
	University	58,22%	2	-7,48%	1	1,5
Computer science	Not specified	4,31%		-57,57%		
	Public sector	16,31%	1	-2,65%	1	1
	Industry	1,54%	2	-69,69%	2	2
	University	77,85%	5	14,45%	5	5
Economics	Not specified	6,02%		-47,64%		
	Public sector	14,46%	1	36,14%	4	2,5
	Industry		1	#DIV/0!	1	1
	University	79,52%	5	2,11%	2	3,5
Energy	Not specified	8,24%		-36,26%		
	Public sector	21,38%	2	12,75%	2	2
	Industry	3,58%	5	-71,38%	2	3,5
	University	66,80%	3	20,13%	5	4
Genomics	Not specified	6,16%		-56,93%		
	Public sector	31,38%	5	25,62%	3	4
	Industry	3,23%	5	130,93%	5	5
	University	59,24%	2	-0,15%	1	1,5
Geo science	Not specified	7,79%		-61,61%		
	Public sector	33,75%	5	37,92%	4	4,5
	Industry	2,97%	4	-8,66%	4	4
	University	55,49%	1	6,74%	4	2,5
Geography (physical)	Not specified	11,78%		26,20%		
	Public sector	18,48%	1	15,47%	2	1,5
	Industry	1,62%	3	21,25%	5	4
	University	68,13%	3	-7,10%	1	2
High Energy Physics	Not specified	8,11%		-37,12%		

	Public sector	25,44%	3	2,83%	2	2,5
	Industry	0,16%	1	#DIV/0!	1	1
	University	66,30%	3	6,30%	4	3,5
Immunology	Not specified	6,86%		-34,38%		
	Public sector	31,86%	5	35,42%	4	4,5
	Industry	2,94%	4	-55,00%	3	3,5
	University	58,33%	2	-1,92%	1	1,5
Information science	Not specified	2,53%		-54,05%		
	Public sector	14,59%	1	13,60%	2	1,5
	Industry	1,75%	3	-4,57%	2	2,5
	University	81,13%	5	1,64%	2	3,5
Innovation studies	Not specified	9,80%		1,06%		
	Public sector	17,65%	1	-9,05%	1	1
	Industry	0,65%	1	-78,10%	2	1,5
	University	71,90%	4	5,87%	3	3,5
Medicine diseases	Not specified	6,67%		-42,07%		
	Public sector	26,82%	3	16,38%	2	2,5
	Industry	2,38%	4	-45,17%	3	3,5
	University	64,12%	3	4,97%	3	3
Nanotechnology	Not specified	6,01%		-15,86%		
	Public sector	24,70%	3	-13,56%	1	2
	Industry	1,64%	3	-90,80%	1	2
	University	67,65%	3	45,71%	5	4
Neuroscience	Not specified	4,19%		-55,26%		
	Public sector	21,20%	2	52,06%	5	3,5
	Industry	0,65%	1	-85,72%	2	1,5
	University	73,95%	4	2,55%	2	3
Organic chemistry	Not specified	4,21%		-51,70%		
	Public sector	16,95%	1	46,31%	5	3
	Industry	2,71%	4	-49,21%	3	3,5
	University	76,13%	4	2,38%	2	3
Pharmacology	Not specified	4,53%		7,80%		
	Public sector	15,33%	1	21,63%	3	2
	Industry	4,18%	5	-44,72%	3	4
	University	75,96%	4	0,43%	2	3
Psychology	Not specified	8,06%		18,20%		
	Public sector	18,09%	1	-35,80%	1	1
	Industry	0,33%	1	-81,91%	2	1,5
	University	73,52%	4	16,36%	5	4,5
Virology	Not specified	4,60%		-67,91%		
	Public sector	27,25%	4	37,85%	4	4
	Industry	2,80%	4	-6,83%	4	4
	University	65,35%	3	3,91%	3	3
Average	Not specified	6,44%		-42,15%		
	Public sector	23,33%		18,27%		
	Industry	2,23%		-53,48%		
	University	68,11%		5,10%		

Exhibit C

Changes of the indicators between 1995 and 2009, shown in percentages.

Field	Authors per paper	Number articles	International co-author	Number countries	Times cited	Public sector	Industry	Universities	Change in keywords	Change in cited journals	Change in countries
Astronomics	87,10%	22,58%	65,22%	28,85%	70,94%	43,93%	-52,69%	3,12%	36,00%	22,67%	6,67%
Biotechnology	37,91%	46,80%	60,57%	36,36%	35,11%	44,06%	-36,76%	0,74%	40,67%	28,00%	20,00%
Climate research	187,97%	77,33%	216,79%	143,75%	50,84%	14,56%	42,01%	2,86%	56,00%	36,67%	33,33%
Computer science	109,60%	40,71%	23,71%	26,92%	43,45%	35,67%	9,03%	-7,48%	47,33%	47,33%	30,00%
Economics	41,53%	3,80%	168,13%	25,00%	41,70%	-2,65%	-69,69%	14,45%	80,67%	38,33%	33,33%
Energy	11,92%	395,27%	-11,35%	137,50%	19,89%	36,14%	No industry in 1995	2,11%	48,00%	43,33%	23,33%
Genomics	5,27%	-73,38%	-5,26%	-10,00%	10,02%	12,75%	-71,38%	20,13%	51,33%	36,00%	40,00%
Geo science	32,74%	37,47%	53,65%	11,11%	26,72%	25,62%	130,93%	-0,15%	40,67%	34,00%	16,67%
Geography (physical)	105,17%	181,40%	111,42%	105,26%	53,65%	37,92%	-8,66%	6,74%	57,33%	46,00%	30,00%
High Energy Physics	9,20%	39,68%	16,54%	11,90%	60,46%	15,47%	21,25%	-7,10%	62,00%	34,00%	20,00%
Immunology	23,46%	8,00%	48,15%	17,65%	-6,89%	2,83%	No industry in 1995	6,30%	57,33%	32,67%	30,00%
Information science	39,48%	238,10%	377,35%	64,00%	86,29%	35,42%	-55,00%	-1,92%	61,33%	60,67%	46,67%
Innovation studies	30,33%	129,17%	292,73%	77,78%	67,77%	13,60%	-4,57%	1,64%	62,67%	46,67%	40,00%
Medicine diseases	64,85%	13,24%	48,71%	40,91%	16,98%	-9,05%	-78,10%	5,87%	64,67%	36,00%	23,33%
Nanotechnology	105,19%	5200,00%	483,02%	600,00%	115,23%	16,38%	-45,17%	4,97%	73,33%	56,00%	40,00%
Neuroscience	66,22%	-8,44%	101,89%	38,10%	20,76%	-13,56%	-90,80%	45,71%	53,33%	30,67%	33,33%
Organic chemistry	18,38%	47,03%	62,79%	31,82%	19,91%	52,06%	-85,72%	2,55%	28,67%	22,00%	23,33%
Pharmacology	33,42%	80,77%	88,37%	92,86%	72,64%	46,31%	-49,21%	2,38%	72,00%	50,00%	30,00%
Psychology	82,47%	51,46%	129,15%	32,00%	18,15%	21,63%	-44,72%	0,43%	56,67%	32,00%	30,00%
Virology	38,09%	56,96%	73,21%	112,12%	5,11%	-35,80%	-81,91%	16,36%	29,33%	24,67%	23,33%
Biochemistry	66,26%	-21,62%	57,04%	27,27%	20,90%	37,85%	-6,83%	3,91%	46,67%	26,00%	20,00%
Average	**55,61%**	**54,97%**	**75,09%**	**53,96%**	**36,28%**	**18,27%**	**-53,48%**	**5,10%**	**53,62%**	**37,32%**	**28,25%**