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Coordination of Large Research Facilities in the Netherlands

Dynamics of knowledge production

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Abstract

The last 10-15 years, many scientific breakthroughs were enabled through large research facilities. However, the Netherlands is weak in coordinating her research facilities. Therefore, this research is conducted to identify what influences the activities of coordination. The activities that are subject to coordination are the incorporation of (external) interests and the extent of flexibility of the research planning. The characteristics of knowledge production are expected to influence these activities. These characteristics vary per scientific fields. Therefore two distinct fields are investigated to identify to what extent the different characteristics influence the coordination activities. The scientific fields that are subject to this study are astrophysics and nanotechnology. This explanatory multi-case study was the first to investigate this relation.

From multiple theories six characteristics of knowledge production are derived and connected to the two activities of coordination. The results of this study prove that large research facilities belonging to nanotechnology are characterized by a higher amount of industrial actors, a higher rate of diversity, a higher rate of interdisciplinarity and a lower collaboration intensity between scientists than facilities belonging to astrophysics. These outcomes are associated with the amount of steering actors, which is higher for the nanotechnology cases. In order to collaborate with these actors, the managers of the large research facilities are pushed to adjust their selection of research topics, which requires a flexible research planning. The activity of the incorporation of (external) interests gave inconsistent outcomes. Consequently, large research facilities are coordinated by the flexibility of research planning. Where the characteristics of nanotechnology cause a flexible research planning and the characteristics of astrophysics cause a more rigid research planning. Based on these findings implications and suggestions for further research are provided.

Keywords: coordination, large research facilities, scientific fields, Mode 2, Triple helix, intellectual and social organization of sciences, search regimes.

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Introduction

Innovation in products and processes strongly influences the economic welfare of a country in a positive way, since new products, services or processes lead to higher profits, higher productivity rates and opportunities to invest (Freeman, 1985; Nelson and Winter, 1977). Innovations are applied by the use of novel knowledge or combining existing knowledge differently than before (Tidd, 2009). Therefore, scientific knowledge development is addressed as a key driver for innovation and as an important resource for economic growth (Conceição et al., 1998; Teece, 2003). Especially in modern western countries, the focus from the production of goods has shifted to the production of scientific knowledge in the last fifty years. These countries act under a 'knowledge based economy', which again proves the importance of scientific knowledge production (Foray and Lundvall, 1996; Godin, 2006; OECD, 2013).

The last 10-15 years, many scientific breakthroughs were enabled through large research facilities, which are called "LRFs" in this study (ESFRI, 2006; Roadmap, 2008). For instance knowledge creation about stem cell therapy at the Center for iPS Cell Research (Kyoto University, 2014) and the increased knowledge base of solar energy by ECN, AMOLF and DIMES (NWO, 2012). The access to LRFs is identified as an important element for countries to play a leading role in knowledge production, causing economic welfare (ESFRI, 2010; Horlings and Versleijen, 2008; Innovatieplatform, 2005; Nooijen et al., 2013; Wijffels, 2004). Because of this, the demand for these types of facilities increased over the last years (ESFRI, 2006; Roadmap, 2008). Large research facilities are defined as "a complex capital good with an advanced technological core that is state-of-the-art at the time of construction" (Horlings et al., 2012, p. 5). For example, an LRF can be a specialized building, like a laboratory, or a set of devices, like telescopes. All types of LRFs have in common that they need at least 40 million Euros in a time period of ten years to be established and maintained (Roadmap, 2008). Since this is generally too high for one actor to fund, most LRFs are funded in multi-institutional and interdisciplinary collaborations (Nooijen et al., 2013). However, all involved funding actors have their own objectives and expectations. Horlings et al. (2012, p. 5) stated about LRFs that "it is a social construct incorporating the objectives and expectations of a diverse range of actors". To be able to integrate all external objectives and select research subjects for the LRF, a strong coordination is required (Cummings & Kiesler, 2007; Hessels, 2013; Lepori, 2011).

As stated previously, the demand for LRFs has increased the past 15 years. Additionally, an increase in the presence of different funding actors, as well as collaborations between scientists with different backgrounds was identified (Etzkowitz & Leydesdorff, 1997; Gibbons et al., 1994). Collaborating with funding actors, like government offices granting subsidies or investments from the industry, is necessary to maintain large facilities. Also, scientists with different backgrounds and perspectives work together to inspire each other and combine their knowledge to create new knowledge, resulting in an increase of interdisciplinary collaboration (Horlings, 2009; Innovatieplatform, 2005; Rhee et al., 2006; Roadmap, 2008). A growing number of studies recognizes this development and points to new ways of knowledge production. They state that the coordination of new scientific research is influenced by these interdisciplinary collaborations and strategic goals with social and economic objectives, whereas the coordination of traditional knowledge production is influenced by merely a single discipline without specific strategic goals (Gibbons et al., 1994; Hessels et al., 2012; Leydesdorff, 2001; Martin, 2010). These different methods of knowledge production are aligned with specific scientific fields (Hessels and van Lente, 2008). The differences are also identified in the organization of LRFs. For instance, in LRFs belonging to a new scientific field, scientists from different disciplines collaborate and funding appears through actors with diverse objectives (AWT, 2007; Horlings, 2009). Differing objectives may interfere or impede each other, which negatively influences the process of decision making, causing a coordination problem in new fields (Hessels, 2012; Lepori, 2011). On the other hand, in LRFs belonging to a traditional scientific field, decision making has to cope with less objectives, causing less intensive coordination. Consequently, it is assumed that the characteristics of knowledge production per scientific field influences different modes of coordination (AWT, 2007; Horlings, 2009). Hence, the differences of coordination and characteristics of knowledge production of LRFs belonging to a traditional and new field are studied. The traditional field is represented by astrophysics, since it is characterized by disciplinary and academic knowledge production with a distinctive defined focus (Heimeriks et al., 2008). As a new scientific field, nanotechnology is chosen, for this field is rapidly evolving through interdisciplinary research and knowledge is produced in the context of application (Heimeriks, 2012; Hessels and Van Lente, 2008; Zucker et al., 2007). Both fields are briefly elaborated on in the next chapter.

In the Netherlands the challenges of coordination are especially high, since the Netherlands is found to be less successful in coordinating facilities when compared to other countries like the UK, Germany, France, Italy, Spain, Sweden and Switzerland (Innovatieplatform, 2005). This might cause a lagging behind of the Netherlands, which can influence economic welfare negatively. However, it is not exactly clear what coordination issues might arise and what field specific bottlenecks and opportunities exist. Therefore, research is needed to identify what coordination activities are present in LRFs and to what extent these activities depend on the characteristics of knowledge creation of these LRFs. Consequently, this study investigates the effect of the characteristics in knowledge production on coordination of LRFs belonging to two distinct fields in the Netherlands, leading to the following research question:

To what extent are different modes of coordination of large research facilities influenced by characteristics of knowledge production in Astrophysics and Nanotechnology in the Netherlands?

This study provides an unique view, since it is the first that investigates the influence of the characteristics of knowledge production on coordination of LRFs. In case this relationship is indeed strong, LRFs could adapt their coordination policy to the characteristics of their belonging scientific field, in order to improve the efficiency of taking decisions and knowledge production (Cummings & Kiesler, 2007; ESFRI, 2010; Innovatieplatform, 2005). Also, the results of this study could be used to expand coordination theories by involving the influential characteristics of institutions. On the other hand, coordination is expected to influence the dynamics of research as well (Hessels, 2013; Lepori, 2011). However, this is beyond the scope of this thesis.

In the following section, the theoretical framework is built to identify the characteristics of knowledge production and the concepts of coordination. From this theory section, hypotheses are presented. Thereafter, the methodology is outlined and finally the results are discussed and conclusions are drawn.

Theoretical framework

This section starts with a brief description of the scientific fields of astrophysics and nanotechnology. Thereafter coordination is defined, followed by a theoretical framework regarding the characteristics of knowledge production. From these theories analytical concepts are identified and connected to coordination. This results in a set of hypotheses and a conceptual model.

Background information

Astrophysics

Astrophysics is a specified branch of astronomy, which applies physics to investigate the universe. The goal of this scientific field is to understand the universe, the creation of galaxies and how planets that are hospitable for life develop. Other focus areas are planets, orbiting stars, dark energy, stars and black holes (NASA, 2012). In order to do research in this field, optical telescopes, infrared telescopes and space-based telescopes (satellites) are used (Harvard, 2013). Hence, this scientific field depends on large research facilities. Furthermore, astrophysics is considered as a traditional scientific field, because it merely involves collaborations within a single discipline and the knowledge production has an academic context (Heimeriks et al., 2008).

Nanotechnology

Nanotechnology is a new scientific field that studies miniscule structures and systems, smaller than 100 nanometers. The goal is to manipulate or exploit these systems to create novel materials, devices and products. This technology can be applied at a wide range of products or processes, like providing renewable energy, clean water and improving health care (OECD, 2013). In order to conduct research, facilities like cleanrooms are needed where the temperature is stable and with isolation from vibrational, acoustic and electromagnetic noise etc. (Penn, 2013). Just as astrophysics, this field depends on large research facilities. However, the patterns of conducting research differ for these fields. As nanotechnology has an interdisciplinary character and knowledge is produced in the context of application (Heimeriks, 2012).

Coordination

Coordination is discussed by multiple scholars and defined in several ways. Lepori (2011, p. 359) defines coordination as "a way of organizing social action in a world where there is no overall mind". The term "social action" is not demarcated, meaning that this definition can include many different activities. In order to research how coordination is influenced by the characteristics of knowledge production, more distinct activities are required to conceptualize coordination. Hessels (2013, p. 322) defined coordination as "the establishment or strengthening of a relationship among the activities in a system, with the aim to enhance common effectiveness." This definition of coordination includes a goal for the activities, which is to reach common effectiveness. However, those goals are not part of this study, since the aim of coordination in this thesis is to reach consensus about which research subjects are selected. Cummings and Kiesler (2007, p. 1622) define coordination as "activities that help project teams integrate and best utilize their expertise". This definition primarily goes into project teams. However, the focus of this thesis is on how coordinating actors integrate (external) demands and select research topics. These coordinating actors can vary from professors, to managers, to CEO's. Combining the aforementioned definitions results in an activity that organizes social action / establishes or strengthens a relationship / helps project teams integrate. For this study, these definitions are translated to the incorporation of (external) interests. The incorporation of (external) interests is an activity that organizes social action, establishes a relationship and helps to integrate. To what extent this activity is applied, is determined by the type of scientific field. As new scientific fields are characterized by multiple (external) demands, more interests are incorporated, which is expected to influence the direction of research. It is expected that the incorporation of multiple interests is complex. However, traditional fields are characterized by less demands, causing less intensive incorporation, less influence and a lower rate of complexity to incorporate (Laudel, 2006).

Furthermore, the coordination of the research planning is also expected to depend on the characteristics of knowledge production. As mentioned, new fields are characterized by multiple actors. In order to collaborate with these steering actors and receive funding, the managers of LRFs are sometimes forced to adjust their selected research topics, which requires a flexible research planning (Mitchell et al., 1997). Gibbons (2000) also pointed out that new scientific fields ask for flexibility of the research planning. He states (p. 37) "The management of a distributed knowledge production process needs to be open-ended, and to break away from classical planning perspectives." Also Kaufmann & Tödtling (2001) and Enders (2005) stated that the changing characteristics of knowledge production, require flexible research planning. Consequently, new scientific fields require a more flexible research planning than traditional fields.

Together, this results in the following two concepts of coordination; incorporation of (external) demands and the extent of flexibility of the research planning. The rate of occurrence of these concepts is influenced by the characteristics of knowledge production, which are derived from the theories about the dynamics of knowledge production and elaborated on in the next sub-chapters. First the theories are discussed separately, to result in six main characteristics that are identified in the theories.

Mode 1 & Mode 2 sciences

Gibbons et al. (1994) were one of the first to identify trends in the way knowledge is produced through time. They pointed out that these trends transform the traditional method, Mode 1, of knowledge production into a highly interactive, less transparent and socially distributed method, Mode 2. All aspects that distinguish Mode 2 from Mode 1 are expected to hamper coordination, since they involve more actors in goal setting or less transparency in quality. Four aspects of Gibbons (1994) are elaborated upon in the following paragraphs. One characteristic, the heterogeneous location of organizations, is excluded, since the location in this thesis is always an LRF.

Academic context – Context of application

Mode 1 knowledge production is organized following academic codes of practice without having a practical goal. However, through knowledge transfer, knowledge from Mode 1 can result in practical applications (Hessels and Van Lente, 2008). Mode 2 knowledge production involves a broad range of considerations and negotiations from various actors. These actors represent supply and demand factors, which give directions for knowledge production. This production process is identified as the context of application (Gibbons et al., 1994). Additionally, these actors mostly aim at rapid results and therefore promote more small and short-term projects. This leads to more diverse topics within LRFs in Mode 2. Furthermore, the promoted projects are very divers, which makes it harder to benefit from earlier work.

Disciplinary - Interdisciplinary

Knowledge production in Mode 2 is created based on multiple disciplines, instead of one discipline in Mode 1. The combination of disciplines asks for new research methods, its own theoretical structures and modes of practice. Furthermore, interdisciplinary knowledge production is characterized by dynamic interactions and the composition of research teams is heterogeneous in terms of skills and experience (Gibbons et al., 1994; Hessels and Van Lente, 2008). As pointed out by Gibbons et al. (1994, p. 6), “in a great wide variety of organizations and institutions the patterns of funding exhibit a similar diversity, being assembled from a variety of organizations with a diverse range of requirements and expectations”. Consequently, patterns of funding are expected to have the same diversity of actors, which influences the coordination.

Autonomy - Social accountability

Gibbons et al. (1994) pointed out that there is a growing awareness that science can affect the public interest. This accounted for an increasing amount of (non-scientific) actors that try to influence the direction of research. These groups take social accountability into account, meaning that they include external demands in defining the problem. This process is identified in scientific fields that belong to Mode 2, since here knowledge is created with application based goals, which enables (non-scientific) actors to see the purpose of science.

Quality control

The quality of knowledge from Mode 1 is determined through peer review judgments. However for Mode 2 a wider set of criteria is needed, caused by a broad range of interest such as social, economic and political interests. According to Gibbons et al. (2008), this wide set of criteria makes it harder to determine “good science”, because multiple judgments should be applied to control the quality of produced knowledge.

Overall, these aspects result in divergent scientific fields without a collective consensus about the direction of research. The lack of consensus within new scientific fields is expected to hamper the process of selecting research subjects within facilities (Whitley, 2000). The following two sections go further into divergent scientific fields.

Intellectual and social organization of sciences

Whitley (2000) made a distinction between scientific fields using two aspects. First, he pointed out that the degree of mutual dependence between researchers varies for traditional and new fields. In traditional fields there is a high degree of mutual dependence, since there are collective goals set for the researchers on which they can rely. In new fields there is a low mutual dependency rate, as the topics are more varied and researchers depend less on each other. The second aspect of Whitley (2000) is about the degree of task uncertainty in producing knowledge and evaluating it. In traditional fields the rate of uncertainty is low, as research is more standardized than in new fields. In new fields there is a lack of consensus about the direction of research, which accounts for numerous research techniques and a diversification of research topics. Consequently, new scientific fields have a low mutual dependency and a high task uncertainty. According to this theory the characteristics of new fields are a lack of collective goals, low knowledge accumulation and larger diversity of topics than in traditional fields (Fry & Talja, 2007; Whitley, 2000).

Search regimes

The theory of Bonaccorsi (2008) goes into the directions of research as well. He described the differences between scientific fields as shifts in "search regimes". These search regimes are defined as "a characterization of dynamic properties of the search processes in a scientific field or discipline" (Bonaccorsi, 2008, p. 310). He applied three aspects to describe the differences between scientific fields; the growth of knowledge production, the extent of diversity and the level of complementarity. In new scientific fields, the growth is expected to be higher, as there is a continuing entry in new fields and research projects are short term oriented. As already mentioned, new fields are more diverse since there is a lack of consensus about the direction of research. Also, new fields are characterized by a high level of complementarity. Complementarity is explained as the need for human input, stemming from different disciplines. In which a high level of complementarity means that an increase in interdisciplinary collaboration is recognized (Bonaccorsi, 2005; Bonaccorsi, 2008). The aspects of Whitley (2000) and Bonaccorsi (2008) together describe how new scientific fields are more divergent, which enlarges uncertainty about future prospects and makes distinct coordination of LRFs harder.

Additionally, an increase in collaboration between industry, university and the government is recognized by multiple scholars (Bonaccorsi, 2008; Gibbons et al. 1994; Leydesdorff, 1995). The following section consists of an elaboration on the Triple Helix theory, which goes into this kind of collaboration.

Triple Helix

The Triple Helix theory describes current knowledge production in a social context in which the relations and communication between university, industry and government play the leading role. Etzkowitz and Leydesdorff (1997) suggested a change in involvement of the government and/or industry in knowledge production, which deviates per scientific field. They expect that universities, industries and the government communicate more in new scientific fields. These actors have their own interests, which increases the difficulty of incorporating all external interests in the selection of research subjects (ESFRI, 2010; Hessels, 2012; Hessels & Van Lente, 2008; Lepori, 2011).

Hypotheses and conceptual model

The theories above identify different characteristics that distinguish traditional scientific fields from new fields. In this section, the main concepts from the theories of Gibbons et al. (1994), Whitley (2000), Bonaccorsi (2008) and Etzkowitz & Leydesdorff (1997) are presented and connected to both concepts of coordination. The concepts of coordination are incorporation of (external) interests and research planning. The conceptual model, in figure 1, presents that coordination is dependent from the characteristics of knowledge production.

Characteristics of knowledge production:

1. Presence of university, industry and government
2. Diversity of topics

3. Knowledge accumulation
4. The extent of interdisciplinarity
5. Growth of knowledge production
6. Collaboration intensity between scientists

Presence of university, industry and government

The first concept addresses collaboration between university, industry and government. Etzkowitz and Leydesdorff (1997) expect a change in involvement of the government and/or industry in knowledge creation per scientific field. Gibbons et al. (1994) agree to this assumption by the notion of context of application, social accountability and quality control. In new fields, scientists incorporate goals from the industry, leading to the context of application. New fields are expected to be characterized by a high rate of social accountability. This translates the needs of the government and society in knowledge development. Quality control is harder in new fields, because criteria from industries and the government need to be taken into account. To sum up: new scientific fields are expected to receive a higher rate of external demands from industries and the government. These demands differ from the demands of internal scientists, since the latter are mostly interested in basic scientific findings, whereas funding actors focus on application oriented research or improved understanding to solve societal problems (Gibbons et al., 1994; Hessels and Van Lente, 2008; Kuhlmann, 2003). Coordination of LRFs has to integrate these demands and it is presumed that, in case of a new field, more demands from the industry and government have to be integrated. This leads to the following hypothesis:

Hypothesis 1

LRFs in nanotechnology are steered by more heterogeneous objectives of industries and the government than LRFs in astrophysics

Additionally, it is expected that the presence of multiple objectives of industries and the government, cause a flexible research planning. The flexibility is needed, in order to cope with different objectives. This leads to the following hypothesis:

Hypothesis 2

A larger presence of industries and the government in LRFs in nanotechnology, in comparison to the presence in astrophysics, causes a research planning that is more flexible for nanotechnology.

Diversity of topics

Bonaccorsi (2008), Whitley (2000) and Gibbons et al. (1994) characterized new scientific fields by their high rate of diversity in topics. A divergent set of topics is thus an important concept for distinguishing fields, agreed on by several theories. Consequently, new scientific fields apply numerous different research projects, which draws the interest of different (external) actors (Laudel, 2006; Lepori & Reale, 2012). Therefore, the extent of incorporation of interests is higher in new fields, caused by the diversity of topics. This leads to the following hypothesis:

Hypothesis 3

The extent of incorporation of interests is higher in LRFs in nanotechnology than astrophysics, caused by a larger diversity in topics for nanotechnology.

Additionally, a high rate of diversity increases uncertainty about future prospects and makes evident research planning more complex. Therefore it is presumed that, in case of a new field, this concept requires flexible research planning, to be able to deviate from the current research topics. This leads to the following hypothesis:

Hypothesis 4

Research planning of LRFs in nanotechnology is more flexible, caused by a diverse set of topics, than research planning of astrophysics.

Knowledge accumulation

This concept is about the extent of dependence on earlier work to create knowledge. Whitley (2000) pointed out that fields that are characterized by various short term projects, have a low rate of knowledge accumulation (Bonaccorsi, 2008; Gibbons et al., 1994). Furthermore, in traditional fields, scientists rely strongly on each other, caused by mutual dependency. If knowledge is based on previous knowledge, a low amount of new actors is incorporated, since the interested actors are already included in the LRFs. This leads to the following hypothesis:

Hypothesis 5

The creation of knowledge in LRFs belonging to astrophysics is based on previous work, causing a low extent of incorporation of interests.

Additionally, if knowledge production strongly relies on earlier work, then less steering is needed; the research methods are evident, norms are set and the direction of research is clear. However, new fields depend less on earlier work. This requires flexible research planning of LRFs, in order to deviate from the research methods and norms set around previous work. This leads to the following hypothesis:

Hypothesis 6

For astrophysics the direction of research depends more on previous work than for nanotechnology, therefore the latter requires a more flexible research planning.

The extent of interdisciplinarity

This concept is about the composition of research teams. Gibbons et al. (1994) stated that the extent of interdisciplinarity of research teams is higher in new scientific fields. Bonaccorsi (2008) also identified interdisciplinary collaborations in new scientific fields, which he conceptualized as a high level of complementarity. Scientists from different disciplines are used to different methods and standards and have different kinds of objectives. Therefore, the incorporation of objectives is assumed to be more complex in new scientific fields than in traditional fields. This leads to the following hypothesis:

Hypothesis 7

Research teams in LRFs of nanotechnology involve an interdisciplinary composition. This results in varying objectives and causes a more intensive process of incorporation of interests, than the incorporation of interests stemming from homogenous research teams in astrophysics.

Furthermore, a high extent of interdisciplinarity makes the process of reconciling interests, of scientists that are used to different methods, more difficult (Cummings & Kiesler, 2007) and causes research planning to be flexible. This leads to the following hypothesis:

Hypothesis 8

Research planning in LRFs belonging to nanotechnology is more flexible, than research planning of astrophysics, caused by a higher rate of interdisciplinarity.

Growth of knowledge production

All theories about the dynamics of knowledge production recognize a growth in knowledge production, however Bonaccorsi (2008) was the only one to conceptualize this characteristic of new scientific fields. He states that the growth is higher as there is a continuing entry in new fields, which causes more actors to be involved in the LRFs. Consequently, this is expected to cause a higher extent of incorporation of interests in new fields, which leads to the following hypothesis:

Hypothesis 9

The extent of incorporation of interests is higher in LRFs belonging to nanotechnology than astrophysics, caused by a continuing entry of new scientist in the field.

Additionally, the growth of knowledge production is caused by short term oriented research projects (Bonaccorsi, 2008), which is also identified in the goals of industries. They favor short-term projects (2-3 years), because then they can quickly receive knowledge about emerging sectors/technologies or new social and economic challenges (Etzkowitz and Leydesdorff, 1997; Gibbons et al., 1994; Laudel, 2006; Lepori, 2011). Short term oriented projects require flexible research planning of LRFs, in order to accept emerging projects and their technologies. This leads to the following hypothesis:

Hypothesis 10

Research planning of LRFs for nanotechnology is more flexible, in comparison to astrophysics, caused by a growing knowledge production.

Collaboration intensity between scientists

Whitley (2000) pointed out that in traditional fields, research teams are expected to be larger than in new fields. This is due to mutual dependency between researchers and collective goals. On the other hand, topics in new fields are more diverse which lowers collaboration intensity and the mutual dependency rate. Research teams with a high degree of mutual dependency have collective goals, which causes that the incorporation of interests is less complex in traditional scientific fields than in new fields. This leads to the following hypothesis:

Hypothesis 11

Research teams in LRFs for astrophysics are characterized by mutual dependency, causing less intensive incorporation of interests than research teams of nanotechnology.

Moreover, steering of research teams with a high degree of mutual dependency and collective goals is easier, which requires less flexible research planning. This leads to the following hypothesis:

Hypothesis 12

Research planning in LRFs belonging to astrophysics is less flexible than research planning of nanotechnology, caused by a higher rate of mutual dependency in astrophysics.

To conclude this chapter, figure 1 presents an overview of the conceptual model. The minus sign presents that the relation between the dependent and independent variable is negative and the plus sign presents a positive relation. The following chapter the methodology is discussed, explaining how these variables are measured.

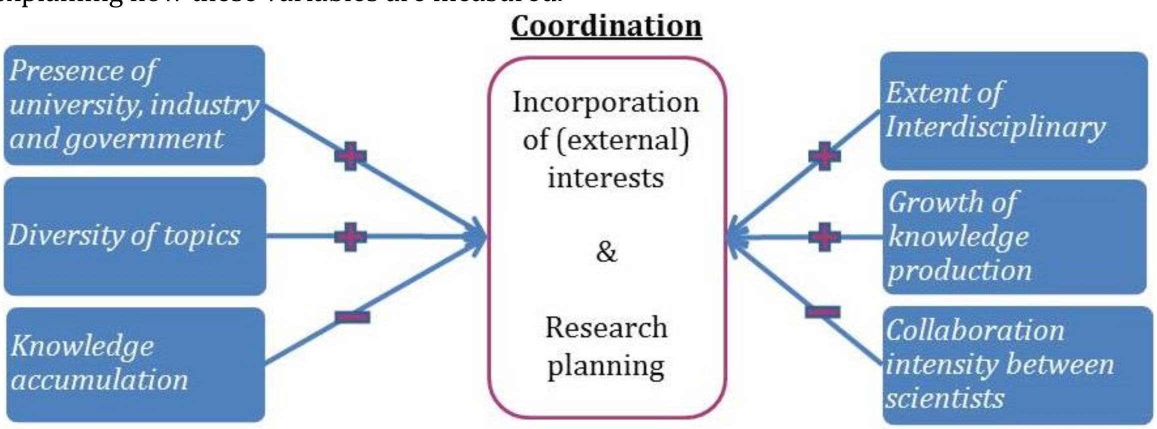

Figure 1: Conceptual Model

Methodology

Research Design

The aim of this thesis is to qualitatively and quantitatively investigate to what extent the coordination of LRFs is influenced by the dynamics of knowledge production. In order to get an in-depth understanding of this effect, a comparative multi-case study is applied. This allows for a focused and thorough analysis as well as a way to test the previously constructed hypotheses in real life situations (Creswell & Clark, 2007; Bryman, 2008). The unit of analysis are LRFs and the subject investigated is how these LRFs are coordinated. The research consists of 3 cases in astrophysics and 3 cases in nanotechnology. These cases are large research facilities that are comparable in investment costs. Using multiple cases provides a basis for comparison and data triangulation, which increases the quality of conclusions and the reliability of the research (Denzin, 1970; Thurmond, 2001; Bryman, 2008). Additionally, comparing the outcomes creates a more complete overview of influential aspects of the dynamics in knowledge production. This study is qualitative in that it investigates how coordination is influenced with an explanatory approach. Additionally, the other part of the analysis consists of a quantitative method, to systematically measure the concepts and compare the cases (Bryman, 2008). The qualitative and quantitative data is analyzed separately from each other. How the data is analyzed is elaborated on in the following sections.

Data Collection

The data for this thesis are collected through interviews with project managers of LRFs and through publication data. Interviews are used as a method to determine the point of view of an interviewee. This gives insight into what the interviewee sees as important concepts that might influence the coordination of LRFs (Bryman, 2008). The interviews in this study are semi-structured, which assures that all interviews follow the same line of questioning but also leaves room for deviation in specific areas (Barriball & While, 1994; Bryman, 2008). Additionally, the interviews include open and closed questions. The open questions provide in-depth information and the closed questions standardize answers.

Moreover, annual reports are used to create a list of publications per case for the years 2008-2012. These publications are downloaded using the Institute for Scientific Information, Web of Science (WoS). As a result, 3 databases of astrophysics and 3 databases of nanotechnology are created. These databases are analyzed separately, to investigate to what extent the proposed concepts are present within the institutions.

Consequently, this paper uses both qualitative and quantitative data analysis. The qualitative part constructs opinions and perspectives about the variables. For example, the interviewees are questioned how decisions are made and what their personal experience is with incorporating external demands. This inductive approach identifies the view of social reality and is used to search for explanations of the outcomes of the quantitative part. The quantitative part emphasizes a deductive approach merely on the independent variables, in which the focus is on testing the hypotheses. Together, these complementary approaches give an in-depth understanding of coordination in LRFs (Kuhlmann, 2003; Lepori & Reale, 2012).

As discussed in the introduction, the research is delimitated to the Netherlands, since the Netherlands has a weak coordination policy.

Operationalization

In order to confirm or reject the hypotheses above, the concepts are operationalized to be able to determine how they influence coordination within LRFs. The concepts from the conceptual model are presented in table 1 below. For each concept indicators are identified to measure them. The interview, survey questions and interpretation schema are presented in appendix III.

Dependent variable

The dependent variable is that of coordination of large research facilities. The goals of this variable are to *incorporate (external) interests* and set a *research planning* (Cummings & Kiesler, 2007; Enders 2005; Gibbons, 2000; Hessels, 2013; Kaufmann & Tödtling, 2001; Lepori, 2011). These are the two concepts of coordination and they are measured qualitatively through interviewing. Integrating (external) interests represents to what extent the LRFs are influenced by (external) actors on selecting their research subjects. The first indicator of this concept identifies which actors influence the institution. The second measures the rate of influence on a Likert scale and the third measures the rate of complexity of incorporating external interests through interviewing. The concept of research planning goes into the flexibility of the time planning of an LRF and determines to what extent the institutions are organized, on an ad hoc basis or by long term planning. The latter aspect implies that the institution is less flexible in accepting new projects.

Independent variables

The independent variables are measured by six concepts as indicated in the conceptual model. The operationalization of the concepts is discussed separately and an overview is presented in table 1.

The first concept, *the presence of university, industry and government* is measured using the indicators:

- The rate of collaboration between universities, industry and the government.
  - Qualitatively by interviewing and on a Likert scale
  - Quantitatively by analyzing research addresses that are coupled to publications
- The rate of funding through universities, industry and the government
  - Qualitatively by interviewing
  - Quantitatively by analyzing funding agencies that are coupled to publications
- Presence of social context objectives, qualitatively by interviewing
- Presence of application context objectives, qualitatively by interviewing

In the two quantitative analyses the addresses and agencies are categorized into university, industry or public sector non-university. The last category represents the government, including public institutions as NWO, STW, FOM, SenterNovem etc. These institutions are included since they operate through governmental missions. Furthermore, all indicators are qualitatively measured by interviewing and the answers are analyzed through selective coding.

The second concept is that of *diversity of topics*. This is measured qualitatively on a Likert scale and through open questioning. This concept is measured quantitatively as well, by analyzing the amount of clusters in the databases, the balance in these clusters and the intensity. The more clusters and the less intensity of these clusters points to a higher rate of diversity. The method for this quantitative analysis is described in the next sub-chapter, the data analysis.

The third concept goes into *knowledge accumulation* within the facility. The indicator for this concept is the extent of new projects stemming from previous projects. This is measured qualitatively on a Likert scale from low to high accumulation and the interviewees are asked to explain their answers. Knowledge accumulation is also measured quantitatively by calculating the cited half-life. This method uses the publication year of the articles that are cited by the databases and determines their median age. A low cited half-life means that knowledge is based on earlier work, thus it represents a high extent of knowledge accumulation (Fuijgaki; 1998).

The *extent of interdisciplinarity* is studied by means of the following indicators:

- Qualitatively by interviewing and on a Likert scale
- Quantitatively by analyzing the WoS categories of articles that cited the database per case
- Quantitatively by analyzing categories belonging to the top 70% citing journals
- Quantitatively by analyzing the Rao-Stirling index

The three quantitative indicators are based on the indicators that Porter & Rafols (2009) used to analyze interdisciplinarity and discussed in the following sub-chapter, the data analysis. Besides, the concept of interdisciplinarity is different from diversity, as the latter does not make a distinction between disciplines but measures the diversity of all the disciplines. Interdisciplinarity however looks at the connections between disciplines.

The fifth concept addresses the *growth of knowledge*, which is measured qualitatively on a Likert scale and through open questioning. This concept is measured quantitatively as well, counting the amount of publications per year, since this represents the creation of new knowledge (McFadyen et al., 2009).

The last dimension is based on *collaboration intensity*, which is quantitatively measured by means of the average amount of authors per publication.

Concept	Indicator	Measurement
Dependent - Coordination of large research facilities		
Incorporation of external interests	Identifying external actors	Selective Coding
	The rate of influence	Likert scale Low influence – high influence
	The rate of complexity	Selective Coding
Research planning	The flexibility of the time planning	Selective Coding
Independent concepts		
Presence of university, industry and government	Rate of collaboration between universities, industries and the government	Selective coding & Likert scale Low rate – high rate
		Quantitatively by analyzing research addresses
	Rate of funding through universities, industry and the government	Selective coding & Likert scale Low rate – high rate
		Quantitatively by analyzing funding agencies
	Presence of social context objectives	Selective coding
	Presence of application context objectives	Selective coding
Diversity of topics	Rate of divergence research topics	Selective coding & Likert scale Low divergence – high divergence
		Quantitative: analyzing clusters, balance and intensity
Knowledge accumulation	Extent of knowledge accumulation	Selective coding & Likert scale Low accumulation – high accumulation
		Quantitative: cited half-life
The extent of interdisciplinarity	Degree of interdisciplinary	Selective coding & Likert scale Disciplinary – interdisciplinary
		Quantitative: WoS categories of articles that cited
		Quantitative: WoS categories of citing journals

		Quantitative: Rao-Stirling index
Growth of knowledge	Extent of knowledge growth	Selective coding & Likert scale Low growth – high growth
		Quantitative: count of publications per year
Collaboration intensity between scientists	Overview of scientists	Quantitative: average of scientists per research teams

Table 1: Operationalization

Data Analysis

The data analysis is conducted to test the hypotheses and to answer the research question. The analysis consists of two parts, qualitative and quantitative analysis, in which the data is analyzed separately from each other, meaning that one research method is not a follow up from the other. This type of mixed research method is called a no sequence concurrent (Creswell et al., 2003). The method is used to strengthen both separate methods. The quantitative results give facts about the concepts and qualitative results explain the facts. In case of contradicting results the quantitative results are dominant, since these present the facts about the institutions. The possible reason for the contradiction are discussed in the discussion.

Qualitative analysis

The qualitative analysis is conducted in two steps: analysis of the closed questions and analysis of the open questions.

The closed interview questions involve an element of self-evaluation by the interviewee to provide a clear perception of their personal evaluation the concepts. The interviewees are asked to answer on a five point Likert scale, which are presented in table 1. The scores that the interviewees give, provide a clear evaluation of their perspective. In the first step of the analysis the scores are compared per LRF for consistency. If the scores are contradicting they are not analyzed further. For example, if two interviewees within the same LRF scored 1 and 5, these results are not reliable for data analysis. After the data is cleaned from inconsistencies it is analyzed, using the averages of the Likert scores. These scores are interpreted in the data analysis as presented in table 2.

Average Likert score	1 – 2,4	2,5 – 3,5	3,6 – 5
Evaluation of concept	Low	Moderate	High

Table 2: Evaluation of Likert score

Subsequently, the Likert scores are used to assess covariances between the dependent variable and independent variables. By comparing the evaluation of the average Likert score of the dependent variable to the independent variables, relations can be identified. For example, if an LRF scores high on the concept "incorporation of external interests", and high on a concept of the independent variable, "degree of interdisciplinary", this could mean that the rate of influence is high when actors from different disciplines collaborate. However, it is also possible that the results are not consistent per scientific field. In that case the independent variable cannot be argued to influence the dependent and the hypothesis is rejected. For each independent variable its relation to the dependent variable is analyzed individually and the hypotheses are confirmed or rejected. The open questions go deeper into the how and why of differences and thus strengthen the established relationships.

Data from the open questions are gathered through recorded interviews. To be able to analyze the answers, excerpts are made of each interview. Irrelevant data is filtered out of the excerpts to create clean data for the Qualitative Data Analysis (QDA). To construct a comprehensive data set, the excerpts are first evaluated per LRF for both interviewees to check the data for consistency. When responses inside an LRF are contradicting, these are indicated as invalid and not analyzed further in the QDA. Then the data is analyzed in a process of selective coding, which involves the integration of all the concepts that have been developed in the theoretical framework. During the selective coding analysis the excerpts are broken down and coded multiple times to reach the core of the answers. The final codes are applied to evaluate the covariances, from the closed questions (Bryman, 2008). Together these results are expected to test the relationships in the hypotheses in a qualitative way.

Quantitative analysis

The quantitative data is gathered through the web of science and imported to Microsoft Access using the bibliometric software tool Saint (Xing et al., 2013). Then the quantitative analysis is applied in a univariate approach, in which one variable is analyzed a time. All quantitative variables are displayed in a frequency table, reflecting the percentages (Bryman, 2008). In case the results of a concept present inconsistencies between facilities belonging to the same scientific field, this concept cannot be argued to influence the dependent variable and the belonging hypothesis is rejected. In order to compare the cases, first each institution is analyzed individually. Subsequently the institutions of astrophysics are compared with nanotechnology to confirm or reject the belonging hypothesis.

Following the analysis of the *diversity of topics* is elaborated on. Through the program Saint Word Splitter (2013) title words are separated and listed. Also commonly used words as “and”, “the” are deleted from this list. Following the list of title words is imported into Access, where preliminary created queries are applied to calculate the amount of clusters. These queries analyze the differences, similarities and proximity of the word stems in order to calculate the Jaccard index. This index presents the rate of similarities between two words. Applying these rates, clusters are constructed. Further the balance is calculated using the following formula (Stirling, 2007, p. 709):

$$\text{Balance}=-\frac{\sum_i p_i \ln p_i}{\ln N}$$

Here P_i is the amount of articles of cluster *i* divided by the total amount of articles. N is the amount of clusters. The balance indicates how articles are divided over the clusters. In which an outcome of 1 means that all the articles are divided equally over the clusters. Also, the intensity of the clusters is calculated by dividing the total amount of articles by the amount of clusters, which presents the average size of the clusters. To conclude, the quantitative results of the diversity present how many different clusters there are per database and how many articles are connected to these clusters. The more clusters and the less intensity of these clusters points to a higher rate of diversity.

Moreover, the quantitative analysis of the *extent of interdisciplinarity* is discussed. First the articles that cited one of the articles of the database were listed through the citation report of the Web of Science. Then the belonging categories to the articles are analyzed. The results present to what extent the citations are divided over other categories, in other words to what extent categories are incorporated in the paper. The second quantitative method listed the top 70% of the citing journals and their belonging categories are indexed as well through the WoS. Finally the Rao-Stirling index was calculated using a program of Leydesdorff (2010). This program uses the WoS categories and determines to what extent the database is characterized by different categories using the equation (Rao, 1992; Stirling, 2007):

$$D = \sum_{ij(i \neq j)} d_{ij} \cdot p_i \cdot p_j$$

This is the sum of coupled disparities, weighted by proportions of categories that are present in the database. The proportion p_i represents the publications citing the most dominant category (i). Where p_j is the proportion of references to one other category (j) and j expresses a different category per summation. The degree of difference between the i and j is d_{ij} and the summation is restricted to non-identical pairs i and j ($i \neq j$). For instance, case A has 30% citing to the dominant category and 20% to a random other category. These categories differ strongly, therefore d_{ij} is high, say 0,7. This gives: 0,3*0,2*0,7= 0,042. This is calculated for all other categories and counted. If a case cited only a couple of other categories, which differ less from each other, the equation and the summation results in a low number.

Eventually the results of the interviews are compared with the results of the quantitative analysis. Together the methods are complementary and strengthen the quality of the research. This is elaborated on in the next section.

Quality Of Research

To determine the quality of this study its reliability, validity and triangulation are taken in account. Triangulation entails applying "multiple observers, theoretical perspectives, sources of data and methodologies" (Bryman, 2008, p. 379). Except for the first aspect, all aspects are included in this thesis. Since three cases per field are investigated in which two interviews are done, the proposed hypotheses are extracted from multiple theories, the data stems from interviews and publications, thus a qualitative and quantitative approach are applied. By applying triangulation, biases of the interviewees and publication data are attempted to be excluded and therefore the quality of the research increases.

Reliability emphases how trustworthy the outcomes of the research are and if they can be repeated by another researcher. The stability of measurement enlarges the reliability, which is applicable to this thesis. All data is gathered and analyzed in a short period and therefore the data is measured in a stable way. Additionally, the decisions about, for instance, translation of data into codes are made by one researcher, which makes the analysis stable. Furthermore, the interviews are recorded, which provides the ability to exactly repeat the interview and enlarge the transparency of the research. Additionally, to increase reliability, this section goes into the methods of analysis that are applied (Bryman, 2008).

Construct validity determines if the concepts addressed in the operationalization are measured correctly. The concepts that are measured in this study, are based on multiple scientific articles. This assures that the concepts are measured properly, which increases the construct validity (Yin, 2003).

External validity investigates if the results can be generalized to a larger population. However, case studies always have a weak external validity. This thesis therefore provides conclusions for the examined facilities only. Nonetheless, it is possible to identify concepts in the dynamics of knowledge production that influence coordination, which can be interesting for future research (Bryman, 2008).

Results

This section presents the results found through this research. The qualitative and quantitative results are discussed per concept and per case. Then the hypotheses are accepted or rejected. A schematic overview of the results is presented in appendix I.

Dependent variable

Coordination of large research facilities is measured qualitatively through the incorporation of (external) interests and research planning. Table 3 and 4 give a summary.

Incorporation of (external) interests

This concept is qualitatively measured by:

- Identifying actors that influence the institutions in selecting their research topics
- The rate of influence in selecting the research subjects on a Likert scale
- The rate of complexity of incorporating external interests

Astrophysics cases

Institution A

Institution A pointed out that they are strongly dependent on subsidies of the government and industries. They collaborate for instance with a multinational, in which they negotiate about common goals. In the survey the interviewees pointed out that they are influenced moderately by external interests in selecting their research subjects. Additionally, respondent A2 said, "It can be complex to make the right decisions. Steering the focus of research is not a problem, but it is a problem to apply all terms." Consequently, institution A is moderately influenced by the government & industry and they experience complexity in incorporating external preconditions.

Institution B

Institution B does not set its own research agenda, The institution has to incorporate the international agenda about astrophysics and has to include the demands of the Dutch astrophysical community as well. The institution has to apply for projects on an international basis, meaning that this sets their research directions. Respondent B1 stated that "I do have a strategy of my own, but 90% of my opportunities are defined by the international community." This is reflected in the survey, which scored high on the rate of external influence. However, the interviewees stated that the incorporation of different interests is not a problem for institution B.

Institution C

Demands of the university and the government are incorporated in institution C. The demand of the university is merely to educate students. Institution C states to feels an acceptable, moderate pressure from the government, since they can chose between multiple governmental institutions that provide subsidies. Additionally, respondent C1 stated that "selecting research subjects is mainly driven through the scientific interest and not by funding agencies." The survey also pointed out that the interviewees are moderately influenced. Furthermore, they pointed out that they do not experience difficulties when they include external demands. However, including these demands hampers them somehow, as respondent C1 said that "We cannot do everything we want, but it is accepted that we are steered in a way." To this comment interviewee C2 added that they cannot meet every precondition, because astrophysics is not as applicable as the government would want; "Astrophysics is a luxury."

Nanotechnology cases

Institution D

External interest from the government, industry and university are incorporated in institution D. To remain interesting for the industry and university, institution D creates new directions of research over the years. For the government they apply an open-access policy to stimulate collaborations. Additionally, the survey pointed out that the institution is influenced by external interests on a high rate. However, including the external demands is not complex for institution D, since their scope is broad and there is enough room to deviate.

Institution E

Institution E depends partly on subsidies of the government, funding from universities and industries. The university merely asks to educate students. The professors decide which subjects are researched and they incorporate interests of the external actors. According to the survey the influence of these actors is high. Respondent E1 stated that the external actors mostly differ in their perspectives from scientists and that incorporation can be complex.

Institution F

Interviewee F1 stated that institution F receives 50% of its income through a long-term governmental contract. He states that this is a high amount, which makes them less dependent on subsidies of the government and funding of industries. Nonetheless, they still have to incorporate external interests, for instance of a multinational industrial partner. These interests influence the institution on a moderate rate, according to the survey. Additionally, the interviewees stated that they are used to incorporate external demands and therefore experience no problems, incorporating external interests.

In table 3 a summary of the outcomes of the dependent variable are presented. As stated in the theory section, the concept of incorporation of (external) interests for nanotechnology institutions was expected to be influenced by more actors, on a higher rate of influence and they were expected to have difficulties including all external demands. It seems that there are indeed more actors involved in nanotechnology and the average rate of influence is high (3,8). However, the average rate of influence is also high for astrophysics (3,7). Consequently, the assumption which states that LRFs belonging to nanotechnology are more (externally) influenced is incorrect. Besides, it seems that one astrophysics institution and one nanotechnology institution have difficulties in incorporating external interests, which gives inconsistency in the scientific fields. Meaning that the assumption which states that incorporation is more complex in the nanotechnology cases is incorrect as well. Though six hypotheses are built on these assumptions and expected that the independent characteristics of the institutions influence them. Since this is not the case, these six hypotheses are rejected.

	Astrophysics			Nanotechnology		
Indicator	Inst A	Inst B	Inst C	Inst D	Inst E	Inst F
Influential actors	Government and industries	90% astrophysics society	University and government	Government, industry and university	Government, industry and university	Government and industries
Rate of influence	Moderate (3)	High (4,5)	Moderate (3,5)	High (4)	High (4,5)	Moderate (3)
Rate of complexity	Complex	No problem	No problem	No problem	Complex	No problem

Table 3: Overview of the incorporation of (external) interests

Research planning

This concept is measured qualitatively through interviewing, focusing on the flexibility of the time planning. An overview of the outcomes is presented in table 4.

Astrophysics cases

Institution A

Research planning in institution A is focused on maintaining a balance in their portfolio regarding long and short term projects. Additionally, respondent A2 pointed out that possible potential knowledge is researched on a small scale. They determine this potential by trend watching in the field of astrophysics and then start new projects. However, these new projects first need to apply for research time in institution A. An independent science committee reviews the applications. Thus institution A uses rules that are set in advance to determine the research planning. This indicates a low rate of flexibility.

Institution B

The research planning is externally determined. Nevertheless, institution B decides for which projects they apply. Most projects are long term oriented and respondent B1 said that “since the projects are long term based, steering of the projects does not happen so frequently.” Concluding, institution B is based on long term projects and is not flexible in selecting research subjects.

Institution C

Professors determine what projects are selected in institution C and the research planning is long term based. The long term based research planning indicates that the institution is not flexible in selecting research subjects.

Nanotechnology cases

Institution D

The research planning of institution D is mainly focused on staying attractive for external parties. In order to do so, every couple of years they create a new interdisciplinary research direction. Also most external projects are accepted, “as long as it is possible in the institution”. In order to accept these projects, the institution is flexible in selecting their research subjects.

Institution E

In institution E the professors set the research planning, which is long term oriented. However the time management of the laboratory happens on an ad hoc basis. Further, most external projects that are in line with the research of the institution are accepted, as institution E can also learn something from these external projects. Projects that are not in line are sometimes accepted, primarily to help one and other. Concluding, this institution selects projects on a more flexible basis than the astrophysics cases. Nevertheless, they are less flexible than institution D, as institution D even selects projects that are out of their scope. Therefore the rate of flexibility of this institution is moderate.

Institution F

The main criterion of setting the research planning for institution F is their scientific interest. Respondent F1 stated "the scientific questions are the coordinator of our institution." Therefore, this institution does not apply preliminary set rules to select research subjects, they set their research planning on an ad hoc basis.

Aforementioned in the theory section the concept of research planning was expected to be more flexible in the nanotechnology cases. As presented in table 4, this expectation is indeed true. Therefore the six hypotheses which expect that the research planning depends on the characteristics of the knowledge production might be accepted and are discussed in the next sub-chapter.

	Astrophysics			Nanotechnology		
Indicator	Inst A	Inst B	Inst C	Inst D	Inst E	Inst F
Flexibility of the research planning	Low rate of flexibility	Low rate of flexibility	Low rate of flexibility	High rate of flexibility	Moderate rate of flexibility	High rate of flexibility

Table 4: Overview of the research planning

Independent variables

Following the six independent concepts and their respective hypotheses are discussed.

Presence of university, industry and government

In this concept the government is indicated as the "public sector non-university", to capture all granting institutions that operate in name of the government, like NWO, STW, FOM etc. An overview of the outcomes is presented in table 5. The concept was measured using the indicators:

- The rate of collaboration between universities, industry and the public sector non-university
  - Qualitatively by interviewing and on a Likert scale
  - Quantitatively by analyzing research addresses that are coupled to publications
- The rate of funding through universities, industry and the public sector non-university
  - Qualitatively by interviewing
  - Quantitatively by analyzing funding agencies that are coupled to publications
- Presence of social context objectives, qualitatively by interviewing
- Presence of application context objectives, qualitatively by interviewing

	Astrophysics			Nanotechnology		
Indicator	Inst A	Inst B	Inst C	Inst D	Inst E	Inst F
Rate of collaboration	Universities & public sector: high Industry: unclear	Universities & public sector: high	Universities & public sector: high	Universities: high Public sector & industry: Moderate	Universities & industry: high Public sector: Moderate.	University: Moderate Industry & public sector: high
Rate of funding	Universities & public sector: high Industry: unclear	Public sector: high	Universities & public sector: high	Public sector: high Industries: high in comparison	Public sector: high Industries: high in comparison	Public sector: high Industries: high in comparison.
Social	Yes	Yes	Yes	Yes	Yes	Yes
Application	Yes	No	No	Yes	Yes	Yes
Total presence of	University & Public sector. Industry: unclear	University & public sector	University & public sector	University, industry & public sector	University, industry & public sector	University, industry & public sector

Table 5: Overview of the presence of university, industry and government

Astrophysics cases

Institution A

The qualitative results of the rate of collaboration between universities, industry and the public sector non-university represent that institution A frequently collaborates with universities and the industry. For instance, they support PhD students, rent their facilities and do research for companies. The industry is also a supplier for institution A, which the interviewees identified as a type of collaboration with the industry. Additionally, the survey pointed out that industrial collaboration appears on a high rate. Further, institution A collaborates with the public sector to receive subsidies. In table 6 the quantitative results are presented. These results present the sum of the three actors, derived from the research addresses belonging to the publications of institution A. The university(47%) and public sector(48%) both scored high. Thus the qualitative results about the industries do not correspond with the quantitative results. To conclude, the rate of collaborations with the universities and public sector are high and the rate of the industry is unclear.

According to the interviewees the funding of institution A is based on the industry(50%) and on the public sector(50%). The quantitative results are presented in table 7. This table shows that the industry only funds 6% and the university funds 11%, which is more than the stated 0%. Thus, funding appears less through the industry and more by the university than the interviewees identified. Concluding, the rate of funding of the public sector is high (71%), the rate of the industry is unclear and in comparison to the other institutions the university rate is high (11%).

Institution A applies several social context objectives, in order to meet the preconditions to apply for subsidies. Meaning that institution A tries to receive subsidies thus collaborates with the public sector non-university. Their application context objectives stem from industrial partners. This implies that they collaborate with the industry.

To conclude, the presence of the government and university is strong and the presence of the industry is unclear. The industry is unclear, since the outcomes are contradicting.

Institution B

Collaboration with universities is tight for institution B and they are located on university grounds. Occasionally they also collaborate with the industry as the interviewees pointed out that less than 5% of the users stem from companies. Respondent B2 states "What we are doing is not even close to making applications, so most firms are not interested." However, institution B uses the industry as a supplier. Through the survey the interviewees pointed out that the collaboration rate with the industry is high. This outcome is not consistent with the interview, as the interviewees identified a low rate of collaboration with the industry. The survey might include the supplier collaborations as well, which is beyond the scope of this thesis, therefore this result is ignored. Furthermore, the institution has tight connections to the public sector, since they have a long term contract with a public institution. In table 6 the quantitative results are presented, which confirm the qualitative results, excluding the survey. Consequently, there are intensive collaborations with universities and the public sector.

According to the interviewees institution B is totally funded by the public sector (ministry of OCW, NWO, STW, FOM etc.). The quantitative results confirm this.

Institution B applies social context objectives, for instance knowledge transfer and valorization. Furthermore, the focus of the institution is not to make applications that can be used in products. These two indicators point out that the government is present and the industry is not.

To conclude, the presence of the university and the public sector is strong. Whereas the industry hardly is present in institution B.

Institution C

The interviewees stated that institution C is part of a university and therefore has an intense collaboration with universities. Almost all users stem from an university. On the other hand, institution C hardly collaborates with the industry. They have some industrial partners, solely to buy goods to construct their instruments. Respondent C2 stated that "in case we would collaborate with a company, we would have a problem. Since they want novel knowledge to be kept secret and we want to write an article about it." This low rate of collaboration was also reflected in the survey. Furthermore, the institution applies for subsidies at the public sector and therefore has a strong connection. In table 6 the quantitative results are presented, which confirm the qualitative results. Hence, institution C has intensive collaborations with universities and the public sector.

The funding of institution C comes from the public sector and the university. The university pays the housing of the institution and the other part of the funding is received through subsidies. The quantitative results are presented in table 7. The funding rate of the public sector non-university is high (92%) and the university scored low (8%). This is due to the fact that payments of housing are not recognized in publications. In comparison to the other institutions, 8% is a high rate of funding, stemming from the university. To sum up, most funding stems from the public sector and the university.

Institution C tries to apply social context objectives, however respondent C1 stated "Astrophysics is a luxury type of science and we cannot always contribute to social goals." The institution has no application context objectives. This implies that there are ties to the government and none to the industry.

To conclude, the presence of the university and the public sector is strong.

Nanotechnology cases

Institution D

The interviewees pointed out that institution D is part of a university and interacts with other universities as well. 60% of the users are from universities and the remaining 40% from the industry. The institution collaborates with the industry in different forms; they rent their facilities partly, they are asked to do research for companies and they stimulate users to establish spin-offs. The survey pointed out that collaborations with the industry happens on a high rate. Also the institution collaborates with the public sector, by applying for subsidies. In table 6 the quantitative results are presented. Here the intensive collaboration with universities is confirmed. Collaboration with the industry is not as high as qualitatively stated, however it is higher than the percentages of astrophysics. Collaboration with the public sector is moderately (22%), comparing it to the other institutions. Consequently, institution D has a high collaboration rate with universities, moderate rate with public sector and moderate with the industry. The funding of institution D comes for 20% from the university, 40% from the industry and 40% from the public sector. The quantitative results show high funding rates in the public sector and the industry. The university is less high, this can be due to the fact that the university finances the buildings and this is not recognized in the publications.

Institution D takes social context objectives into account through a research team that goes into ethics. Furthermore, the institution does research to improve the health care and is aware that they can mean something for the Dutch society. In the institution users are stimulated to do research that can be applied in a product or process. So they have a strong focus on application context objectives. Meaning that institution D has strong ties with the public sector and the industry.

Taking the indicators together, the presence of the university, industry and government is strong. All three actors are intensively involved in institution D.

Institution E

Institution E is part of an university, which means that their collaboration is intense. 66% of the users are from universities and 33% from the industry. Institution E collaborates with multinationals in different kinds of partnerships. They rent their facilities partly, they visit companies to collaborate in research and they are asked to do research for companies. The interviewees stated that they would like more collaborations with the industry, which is reflected in the answer to the survey. They pointed out that the rate of collaboration with the industry is moderate. Furthermore, institution E collaborates with the government, by applying for subsidies. In table 6 the quantitative results are presented. This confirms that the collaboration with the university is intense and that the collaboration with the public sector is moderate. The collaboration rate of the industry is high, in comparison to the other institutions. This does not resemble the outcome of the survey. However, the outcome of the survey reflects the fact that institution E is able to grow, not the fact that the collaboration rate is already high. To conclude, the rate of collaboration with the public sector is moderate, the universities and industry is high.

According to the interviewees funding of institution E comes for 33% from the university, 33% from the industry and 33% from the public sector. The quantitative results present less industry and university than the interviewees stated, however the rates of the industry are still high in comparison. The university is probably not reflected in the quantitative results since the university finances the building and this is not recognized in the publications.

Caused by external pressure institution E is social responsible. They for instance stimulate companies in making new products and partly focus on health care subjects. Institution E has application context objectives as respondent E1 stated "We are not a production firm, but we prove that something works and then the industry takes over. We call that proof of concepts." This implies that there are strong ties to the government and the industry.

Together, the indicators reflected a high presence of the university, industry and government.

Institution F

The interviewees stated that institution F collaborates frequently with universities and the industry. They apply four forms in collaboration with the industry as well, in order to stimulate this cooperation. The survey pointed out that the rate of collaboration with the industry is moderate. Additionally, the collaboration with the public sector is tight, because institution F has a long term contract with a subsidy agency. In table 6 the quantitative results are presented. In comparison there is an intensive collaboration with industries and the public sector. The university is moderately present in collaborations. Further, the interviewees pointed out that the funding of institution F comes for 85% from the public sector an 15% stems from the industry. The quantitative results nearly confirm this.

Institution F takes social context objectives into account by "being strategic for the Netherlands" (respondent F1) and by presenting their knowledge to others. The application context objectives of the institution stem from the industry, thus are externally determined. Meaning that institution F has strong ties with the public sector and the industry.

To conclude, the presence of the industry and government is strong. Especially the public sector is intensively involved.

Category	A: % of 1071	B: % of 1198	C: % of 2114	D: % of 1459	E: % of 381	F: % of 961
University	47%	44%	54%	72%	78%	35%
Industry	2%	3%	1%	5%	11%	7%
Public sector non-university	48%	53%	45%	22%	10%	57%
Other	3%	0%	0%	0%	0%	1%

Table 6: Quantitative results of the research addresses

Category	A: % of 722	B: % van 1391	C: % of 4011	D: % of 9019	E: % of 105	F: % of 684
University	11%	2%	8%	0.3%	1%	3%
Industry	6%	0%	0.4%	18%	16%	10%
Public sector non-university	71%	97%	92%	81%	82%	84%
Other	11%	1%	1%	0.1%	0%	3%

Table 7: Quantitative results of the funding agencies

Hypothesis 1

LRFs in nanotechnology are steered by more heterogeneous objectives of industries and the government than LRFs in astrophysics.

For this hypothesis the presence of universities, industries and the government was analyzed and an overview about the independent concept is presented in table 5, in which the column "Total presence of" represents the outcome of this concept. To accept or reject hypothesis 1, these outcomes have to be compared to the concept of incorporation of (external) interests. As pointed out, the concept of incorporation gave inconsistent outcomes and proves therefore not to be influenced by independent concepts. However, if the inconsistent outcomes are excluded, one indicator remains. This indicator analyzed which actors are incorporated in selecting research subjects. To be able to partly accept or reject hypothesis 1, only this indicator of the dependent variable is used.

In institution A the independent concept states that the government (strongly), university (moderate) and industry (unclear) are presented. As shown in table 3, actors that are incorporated in selecting research subjects in institution A are the government and industry. Since institution A does not incorporate interests from the universities, the independent concept does not seem to fully influence the dependent concept. In institution B the university and the public sector are present. They incorporate the Dutch astrophysical community and the international agenda. The latter is set by international public sectors and the first by scientists. For institution B the independent concept resembles the dependent concept, meaning that the independent concept might influence the dependent concept. In institution C the university and the public sector are present. The interests from these actors are incorporated as well. Thus the relation between the independent concept and the dependent concept is positive. In institution D and E the university, industry and the public sector are present. All actors are also incorporated in the coordination process. The relation between the independent and dependent concepts is positive. Institution F does not incorporate interests from universities, meanwhile they are moderately presented in the institution. Consequently, the independent concept influences the dependent concept in four of the six cases. This means that the independent concept does not fully influence the dependent concept, thus the hypothesis cannot be accepted.

Furthermore, the hypothesis compares nanotechnology and astrophysics, stating that the presence of industries and the government in nanotechnology is higher than the presence in astrophysics cases. The outcomes present that astrophysics is characterized three times by the university, three times the government and one time the industry. Whereas all three nanotechnology cases are characterized by the university, the government and the industry. Consequently, the LRFs belonging to nanotechnology are characterized by a higher presence of the industry than LRFs belonging to astrophysics. Nevertheless, there are too many inconsistences to confirm the hypothesis, therefor hypothesis 1 is rejected.

Hypothesis 2

A larger presence of industries and the government in LRFs in nanotechnology, in comparison to the presence in astrophysics, causes a research planning that is more flexible for nanotechnology.

This hypothesis examines the effect of the presence of industries and the government on the flexibility of setting a research planning. Aforementioned, the LRFs belonging to nanotechnology are characterized by a higher presence of the industry than LRFs belonging to astrophysics. However the presence of the government was the same in both fields. As presented in table 4, the LRFs belonging to nanotechnology are more flexible in their research planning than the astrophysics cases. Consequently, it can be argued that the presence of industries cause a higher rate of flexibility of the research planning. For that reason, this hypothesis is partly accepted.

Diversity of topics

This concept was measured using the indicators:

- Qualitatively by interviewing and on a Likert scale
- Quantitatively by analyzing the amount of clusters, the intensity of these clusters and the balance in the clusters (Stirling, 2007)

Astrophysics cases

Institution A

Respondent A2 stated that the spectrum of subjects is limited. This is reflected in the survey as well, since the interviewees scored their institution moderate in the rate of general diversity and low on the diversity within disciplines. In table 8 the quantitative results are presented. There are 20 clusters identified with the average of 28,60 publications per cluster. The balance is 0,45, which means that the publications are not equally divided over the clusters. However, this skewness accounts for all institutes. Comparing the amount of clusters and the intensity to the nanotechnology cases, institution A has a low amount of clusters and a high intensity. To sum up, both the qualitative and quantitative results prove that institution A is not diverse in their research topics. An illustration of the diversity of institution A is presented in figure 2. This picture shows strong ties between the publications and a low proximity between the clusters of publications.

Institution B

Both respondents stated that their institution is not diverse. Repsondent B1 said “the diversity of our research subjects is low, due to the fact that we do not construct that many instruments.” Currently institution B works on 5 projects. Additionally, respondent B2 said “we are an expertise institute, we only do projects in this expertise.” Both survey questions were scored moderate. The quantitative outcomes confirm that institution B has a low rate of diversity, since the amount of clusters (20) is low and the intensity is high (32,15). Ergo, the diversity of institution B is low.

Institution C

In institution C the topics are coupled to the research direction of the professors, implying that the diversity is low. However, respondent C2 said “there are many different sub-disciplines in the astrophysics in which the professors do research.” The survey pointed out that the diversity of subjects is moderate and the diversity within disciplines is moderate as well. This is reflected in the amount of clusters identified in the quantitative analysis. There are 28 clusters, which is higher than the amount in institution A and B, nonetheless it is still lower than the nanotechnology institutions.

To conclude, the results showed a lower rate of diversity than the nanotechnology cases.

Nanotechnology cases

Institution D

Institution D has more than 30 different research directions that have a slight overlap. Additionally, they save a part of their capacity for possible external projects, which can diverge from the internal subjects. This is reflected in the survey as well, since both questions were scored high. The quantitative results confirm the qualitative statements, as there are 70 clusters with an average of 15,19 publications. Consequently, institution D is characterized by a high extent of diversity.

Institution E

Just as institution D, has institution E 30 research directions with a slight overlap. External subjects can vary from the internal subjects and both survey questions were scored high. Again, the quantitative results identified more clusters (33) with a lower intensity (9,42), than the astrophysics cases. To conclude, institution E is highly diverse.

Institution F

Institution F applies subjects that are diverse and they accept projects that are not in line with internal projects. This is reflected in the survey questions, as institution F scores high on both. In table 8 the quantitative results are presented. These confirm the qualitative results, as there is a high amount of clusters (38) with a low intensity (14,84). Therefore, institution F also has a high rate of diversity in topics. An illustration of the diversity of institution A is presented in figure 3. This picture shows some ties between the publications and a high proximity between the clusters of publications.

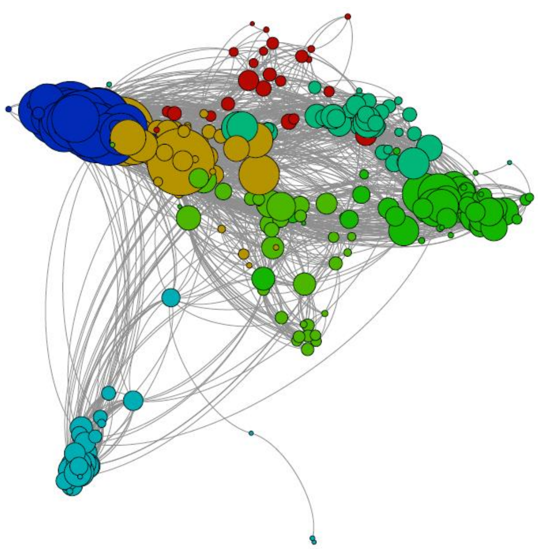

Figure 2: Diversity of astrophysics

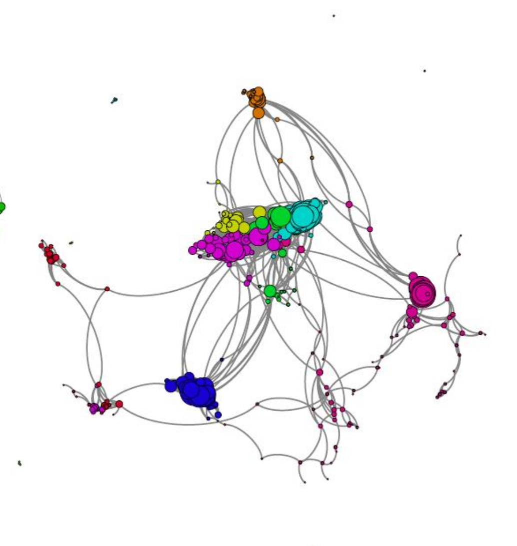

Figure 3: Diversity of nanotechnology

	Clusters	Balance	Intensity
Inst. A	20	0,45	28,60
Inst. B	20	0,35	32,15
Inst. C	28	0,33	41,43
Average Astro	23	0,38	34,06
Inst. D	70	0,52	15,19

Inst. E	33	0,50	9,42
Inst. F	38	0,53	14,84
Average Nano	47	0,52	13,15

Table 8: Diversity (Stirling, 2007)

Hypothesis 3

The extent of incorporation of interests is higher in LRFs in nanotechnology than astrophysics, caused by a larger diversity in topics for nanotechnology.

Hypothesis 4

Research planning of LRFs in nanotechnology is more flexible, caused by a diverse set of topics, than research planning of astrophysics.

Firstly, the diversity of astrophysical cases are compared with the nanotechnology cases. It was expected that the nanotechnology institutions study a more diverse spectrum of topics. Looking at the qualitative and quantitative results, this statement is accepted, as the average of clusters for nanotechnology is higher (47 to 23) and the intensity is lower (13 to 34). The outcome of the balance is not included in explaining the rate of diversity, since this was almost similar through the cases. Additionally, an illustration of the diversity of one astrophysics and one nanotechnology institution is presented in figure 2 and 3. This illustration shows that astrophysics has stronger ties between the publications and that the proximity is lower. On the other hand, the clusters of nanotechnology are more separated and some publications are not connected to others at all. To sum up, the diversity of topics is higher in an LRF belonging to nanotechnology. The illustrations are captured on the same zoom distance and edited using the same options.

Secondly, the relation between the independent and dependent concepts is examined. As presented, the concept of incorporation is inconsistent, thus cannot be caused by the consistent rate of diversity. Therefore hypothesis 3 is rejected. Furthermore, the diversity of nanotechnology is expected to cause flexibility in the research planning. As presented in table 4 the institutions belonging to nanotechnology are indeed more flexible than the institutions belonging to astrophysics. Therefore the relation between the diversity and the research planning proves to be positive and hypothesis 4 is accepted.

Knowledge accumulation

This concept was measured qualitatively by interviewing, on a Likert scale and quantitatively by the cited half-life.

Astrophysics cases

Institution A

The interviewees pointed out that the extent of knowledge accumulation is high. Which is reflected in the survey. Quantitatively the cited half-life is measured. For institution A the cited half-life is 8 years, which means that 50% of the cited articles by institution A are from 2005 till 2012. The remains are from before 2005. The lower the cited half-life is, the more knowledge is based on earlier work.

Institution B

Interviewee B2 stated that knowledge creation strongly depends on former knowledge. Interviewee B1 pointed out that projects can take 12 till 14 years in which knowledge is created using earlier work. Additionally the survey presents a high rate for knowledge accumulation as well. The cited half-life of institution B is 9 years. This means that 50% of the cited articles by institution B are from 2004 till 2012.

Institution C

The extent of knowledge accumulation is high at institution C, as respondent C1 pointed out "Solving a problem, causes new questions." Also the survey presents a high rate of knowledge accumulation. The cited half-life of institution B is 9 years, just as institution B.

Nanotechnology cases

Institution D

The extent of knowledge accumulation is high in institution D, since the survey presented a high rate. The cited half-life of institution D is 9 years.

Institution E

The interviewees of institution E pointed out that the knowledge accumulation is high. That is also reflected in the survey. The cited half-life of institution E is 8 years.

Institution F

In institution F is the extent of knowledge accumulation high. Also, the survey presents a high rate of knowledge accumulation. The cited half-life of institution F is 9 years.

Hypothesis 5

The creation of knowledge in LRFs belonging to astrophysics is based on previous work, causing a low extent of incorporation of interests.

Hypothesis 6

For astrophysics the direction of research depends more on previous work than for nanotechnology, therefore the latter requires a more flexible research planning.

For both hypotheses the knowledge accumulation was measured and then compared to the extent of incorporation and the flexibility of research planning. However, all cases represented a high extent of knowledge accumulation, which means that the expected differences between astrophysics and nanotechnology are not correct. Consequently, the dependent and independent concept in hypothesis 5 do not occur as expected, causing a rejection of the hypothesis. Additionally, it was expected that a low rate of knowledge accumulation would require a high extent of flexibility. As presented in table 4, nanotechnology is more flexible in their research planning than astrophysics. However, all cases identified a high rate of knowledge accumulation, which means that the independent variable does not influence the outcome of the dependent variable. Therefore hypothesis 6 is rejected as well.

The extent of interdisciplinarity

Interdisciplinarity is researched by means of the following indicators and a schematic outcome is presented in appendix II:

- Qualitatively by interviewing and on a Likert scale
- Quantitatively by analyzing the WoS categories of articles that cited the database per case
- Quantitatively by analyzing categories belonging to the top 70% citing journals
- Quantitatively by analyzing the Rao-Stirling index

Astrophysics cases

Institution A

The interviewees of institution A pointed out that the internal knowledge varies over the technology chain, from constructing instruments to writing software. This implicates that they are interdisciplinary oriented. This is reflected in the survey, where institution A scored high on the rate of collaboration between scientists with different backgrounds. Additionally, the survey asked how many disciplines are present in the institution, the average score is 3,5.

Quantitatively the database of institution A is analyzed, through the citation report and the belonging categories. Meaning that the categories of the articles that cited an article from the database are listed. The top 5 categories are presented in table 9. These results show that most articles (68%) that cited the database belong to the Astronomy Astrophysics category and that the distribution over the other categories is small.

Furthermore, the top 70% of the cited journals by the database were listed and their belonging categories were indexed. The top 5 categories are presented in table 10. It took institution A 9 journals to reach the 70%. In this range most journals (86%) belonged to the Astronomy Astrophysics category and 16 categories were identified in total. These other categories were less represented and the distribution is small.

Finally, the Rao-Stirling index was calculated by a program of Leydesdorff (2010). Institution A has an index of 0,30. The closer to 1 this number is, the more interdisciplinary the institution is.

To conclude, the qualitative results stated that institution A is interdisciplinary and the quantitative results prove the contrary. Since the quantitative results present low outcomes over three distinct methods, these results are dominant and prove that institution A has a low extent interdisciplinary.

Institution B

In institution B the internal users vary from scientists, engineers and technicians. The interviewees pointed out that their users originate from several disciplines. The survey resulted in a high extent of collaboration between users with different backgrounds and the average amount of disciplines that are present in the institution is 3,5.

In table 9 the top 5 categories of the articles that cited an article from the database are listed. The majority of the articles (76%) that cited the database belong to the Astronomy Astrophysics category and the distribution is small. In table 10 the top 5 categories belonging to the top 70% of the citing journals are listed. It took 21 journals to reach the 70%, in which 20 categories were identified. The distribution over these categories is small and most journals belong to the same category, Astronomy Astrophysics (79%). Further, the Rao-Stirling index of institution B is 0,61.

To conclude, institution B is connected to mainly one category. However the qualitative results and the Rao-Stirling index illustrate that the institution is interdisciplinary to some extent. Together this gives a moderate rate of interdisciplinarity.

Institution C

In institution C users from astrophysics and chemistry use each other's instruments. The survey pointed out that the rate of interdisciplinary collaborations is moderate and the average of identified disciplines is 3,5.

In table 9 the top 5 categories of the cited articles are listed. Most articles (88%) belonged to the Astronomy Astrophysics category and the distribution is small. Again the top 70% of the citing journals were listed and their belonging categories indexed. For institution C only one category was used and it took 4 journals to reach the 71%. In table 10 the result is shown. Additionally, the Rao-Stirling index is 0,20.

To sum up, the qualitative results presented a moderate rate of interdisciplinarity and the quantitative results a low rate. Since the quantitative results are measured by three distinct independent methods, these results are dominant. Therefor institution C has a low rate of interdisciplinarity.

A: WoS Categories	A: % of 6342	B: WoS category	B: % of 5549	C: WoS category	C: % of 13324
Astron Astroph	68%	Astron Astroph	76%	Astron Astroph	88%
Phys Part Fields	14%	Meteo Atmos Sci	11%	Phys Part Fields	3%
Phys Multidisci	5%	Phys Part Fields	7%	Phys Atom Chem	2%
Phys Nuclear	4%	Phys Applied	7%	Phys Multidisci	2%
Phys Applied	3%	Geosci Multidisci	6%	Multidisci Sci	1%

Table 9: WoS categories through citation report

A: WoS Categories	A: % of 24145	B: WoS category	B: % of 18639	C: WoS category	C: % of 52123
Astron Astroph	86%	Astron Astroph	79%	Astron Astroph	100%
Multidisci Sci	4%	Meteo Atmos Sci	7%		
Phys Part Fields	4%	Multidisci Sci	5%		
Spectroscopy	1%	Optics	2%		
Nucl Sci Techn	1%	Geosci Multidisci	2%		

Table 10: WoS category of journals

Nanotechnology cases

Institution D

Being interdisciplinary is part of the policy of institution D. They create new directions of research every couple of years by connecting existing directions from different disciplines. This is reflected in the survey as well, since institution D scored high and identified an average of 6 disciplines. In table 11 the top 5 categories of the cited articles are listed. There is a high distribution over the categories, meaning that institution D researches multiple categories. The top 70% of the citing journals were listed as well and their belonging categories indexed. It took 124 journals to reach the 70%, in which 39 categories were identified, as presented in table 12. The rate of distribution over these categories high, since the journals belong to different or multiple categories. Additionally, the Rao-Stirling index is 0,48. Concluding, both the qualitative and the quantitative results present a high rate of interdisciplinarity.

Institution E

The internal users of institution E differ in their scientific backgrounds. One of the interviewees stated that at least four disciplines are recognized. The survey resulted in a high extent of collaboration between scientists with different backgrounds and the average of identified disciplines is 3,5. In table 11 the top 5 categories that belong to the articles which cited the database of institution E are listed. The articles are connected to a broad spectrum of categories. In table 12 the top 5 categories belonging to the top 70% of the citing journals are listed. It took 360 journals to reach this percentage, in which 45 categories were identified. This means that there is a very high rate of distribution over these categories. Further, the Rao-Stirling index is 0,50. To sum up, the qualitative results present a high rate of interdisciplinarity, however the extent of identified categories is comparable to the astrophysics cases. The quantitative results present that institution E is broadly divided over many categories. Taken together, institution E has a high extent on interdisciplinarity.

Institution F

Institution F pointed out that their research subjects originate from different disciplines and that these disciplines are connected as well. This is reflected in the survey, where institution F scored high. The average amount of recognized disciplines is 4. The quantitative results showed that institution F is highly divided over the categories of the WoS. The top 70% of all cited journals was reached in 70 journals and gave 43 distinct categories. This means that institution F is recognized in a very broad spectrum of categories in the WoS. Further, the Rao-Stirling index is 0,52. Consequently, the qualitative and quantitative results both present a high extent of interdisciplinarity in institution F.

D: WoS Categories	D: % of 15714	E: WoS category	E: % of 1844	F: WoS category	F: % of 14521
Matsci Multidisci	16%	Phys Applied	19%	Optics	16%
Phys Applied	15%	Matsci Multidisci	18%	Phys Applied	14%
Phys CondMat	13%	Nanosci Nanotech	12%	Chem Phys	14%
Chem Phys	13%	Engin EE	12%	Matsci Multidisci	14%
Chem Multidisci	12%	Chem Phys	10%	Nanosci Nanotech	10%

Table 11: WoS categories through citation report

D: WoS Categories	D: % of 47542	E: WoS category	E: % of 281941	F: WoS category	F: % of 24771
Phys CondMat	13%	Engin EE	19%	Chem Phys	10%
Chem Phys	11%	Phys Applied	16%	Phys Multidisci	9%
Chem Multidisci	11%	Matsci Multidisci	10%	Phys Applied	9%
Phys Applied	11%	Phys CondMat	10%	Multidisci Sci	9%
Matsci Multidisci	10%	Nanosci Nanotech	7%	Phys Atom Chem	8%

Table 12: WoS categories of journals

Hypothesis 7

Research teams in LRFs of nanotechnology involve an interdisciplinary composition. This results in varying objectives and causes a more intensive process of incorporation of interests, than the incorporation of interests stemming from homogenous research teams in astrophysics.

Hypothesis 8

Research planning in LRFs belonging to nanotechnology is more flexible, than research planning of astrophysics, caused by a higher rate of interdisciplinarity.

For these hypotheses the rate of interdisciplinarity per institution is measured. In appendix II an schematic overview is presented in which the column "total extent" represents the outcome. The results show that all nanotechnology cases are highly interdisciplinary, that two astrophysics cases have a low extent and one a moderate. This means that nanotechnology is more interdisciplinary in nature than astrophysics. In hypothesis 7, this outcome is compared to the incorporation of interests. As stated, the outcomes of this dependent concept varies per case, thus a comparison cannot be made. To conclude, hypothesis 7 is rejected.

Hypothesis 8 states that a high extent of interdisciplinarity causes a flexible research planning. The outcome of this dependent variable is high in the nanotechnology cases. Consequently, the relation between the independent variable and dependent variable is positive and hypothesis 8 is accepted.

Growth of knowledge

This concept was measured using the indicators:

- Qualitatively on a Likert scale
- Quantitatively by comparing the amount of publications per year, where 2008 is the starting point

Astrophysics cases

Institution A

The survey showed a moderate growth of publications and an interviewee added that due to new instruments they sometimes grow stronger and sometimes are more stable. In table 13 the quantitative results are presented. From this it is confirmed that the knowledge base of institution A is growing.

Institution B

The interviewees scored their institution high looking at the knowledge production. However interviewee B1 stated that previously they could construct a new instrument every five to six years, but due to a decrease in their budget this shifted to one instrument per 20 years. The quantitative results are fluctuating. To sum up, institution B is not growing and the amount of publications fluctuates per year.

Institution C

Institution C scored high in the survey and interviewee C1 stated "the last 15 years we approximately duplicated, caused by collaborations with other laboratories." Also, the quantitative results identified a growth in publications.

	Inst. A		Inst. B		Inst. C	
Year	Article Count	2008=100	Article Count	2008=100	Article Count	2008=100
2008	58	100	101	100	163	100
2009	84	145	105	104	181	111
2010	97	167	179	177	241	148
2011	137	236	98	97	239	147
2012	162	279	160	158	336	206

Table 13: Amount of publications (astrophysics)

Nanotechnology cases

Institution D

Institution D scores high in the survey and interviewee D1 added that they develop new research teams every couple of years. Meaning that the amount of users is growing. In table 14 the quantitative results are presented. These confirm that the knowledge base of institution D is growing.

Institution E

In the survey the interviewees pointed out that the knowledge growth is moderate. They stated that there is room for more users, hence they have a potential to grow. Meanwhile, their large capacity causes a fluctuating amount of users. Table 14 confirms this statement.

Institution F

Institution F points out to be stable in their knowledge growth, since they reached their maximum capacity. This is also confirmed by the quantitative results.

	Inst. D		Inst. E		Inst. F	
Year	Article Count	2008=100	Article Count	2008=100	Article Count	2008=100
2008	137	100	59	100	101	100
2009	179	131	51	86	110	109
2010	223	163	61	103	104	103
2011	250	182	56	95	135	130
2012	272	199	84	142	114	110

Table 14: Amount of publications (nanotechnology)

Hypothesis 9

The extent of incorporation of interests is higher in LRFs belonging to nanotechnology than astrophysics, caused by a continuing entry of new scientist in the field.

Hypothesis 10

Research planning of LRFs for nanotechnology is more flexible, in comparison to astrophysics, caused by a growing knowledge production.

In order to accept or reject these hypotheses, first the entry of new scientists is measured by means of knowledge production. This results in the following; institution A is growing, B fluctuates, C is growing, D is growing, E fluctuates and F is stable. This means that a comparison between astrophysics and nanotechnology does not prove the preconceived statement. Therefore hypotheses 9 and 10 are rejected.

Collaboration intensity between scientists

This concept was only measured on a quantitative base, listing the average amount of authors per publication. This resulted in high numbers for the astrophysics cases and it seemed that some articles in these cases are characterized by hyper authorship. This skewness asked for another measure, therefore the median was added.

Astrophysics cases

Institution A

The quantitative results are presented in table 15. Interviewee A2 stated that "when a new instrument is constructed, many potential users want to use it. Since the capacity is too small for this, they team up and you'll see large research teams." To conclude, the collaboration intensity is high in institution A.

Institution B

As is presented in table 15, the collaboration intensity of institution B is high. An interviewee pointed out that the research teams can consist of 100 to 200 users.

Institution C

Institution C has a high collaboration intensity looking at the quantitative results. Interviewee C2 stated that they collaborate in large research consortia, confirming the quantitative results.

Nanotechnology cases

Institution D, E & F

The quantitative results of these three institutions are almost the same. All have smaller average research groups and the median is also lower in comparison to astrophysics.

	Astrophysics			Nanotechnology		
	Inst. A	Inst. B	Inst C.	Inst. D	Inst. E	Inst. F
Average	40	19	11	4	4	4
Median	7	6	6	3	4	3
Lowest	1	1	1	1	1	1
Highest	675	257	208	25	19	24

Table 15: Amount of authors per publication

Hypothesis 11

Research teams in LRFs for astrophysics are characterized by mutual dependency, causing less intensive incorporation of interests than research teams of nanotechnology.

Hypothesis 12

Research planning in LRFs belonging to astrophysics is less flexible than research planning of nanotechnology, caused by a higher rate of mutual dependency in astrophysics.

These hypotheses compare the mutual dependency of astrophysics with nanotechnology. The mutual dependency is measured by means of the amount of authors per publication. The results showed that the research teams in astrophysics are larger than the teams of nanotechnology. Thus the first part of hypothesis 11 is accepted. The second part connects the independent characteristic to the incorporation of interest. This connection cannot be confirmed, since the outcome of incorporation is inconsistent. Therefore hypothesis 11 is rejected. Hypothesis 12 states that flexibility is decreased by a higher amount of collaborating scientists. This negative relation is established, looking at the results. Therefore, hypothesis 12 is accepted.

Conclusion

This thesis identified six characteristics that distinguish traditional and new scientific fields and studied the appearance of these concepts in large research facilities. It was expected that the facilities connected to a traditional or new field have the same characteristics as their scientific field. Then it was assumed that the characteristics of scientific fields influence the process of coordination. The coordination process distinguishes two concepts; the incorporation of (external interests and research planning. This was studied using the following research question:

To what extent are different modes of coordination of large research facilities influenced by characteristics of knowledge production in Astrophysics and Nanotechnology in the Netherlands?

In order to answer this question, first the characteristics that did not appear as they were expected are mentioned as well as one of the concepts of coordination that differed from the expectations. Finally, the extent of influence of the independent characteristics on coordination is elaborated on. An overview of the outcomes is presented in table 16.

Concept	Astrophysics	Nanotechnology
Presence of university, industry and government	Industry is less present	All present
Diversity of topics	Less diverse	Highly diverse
Knowledge accumulation	*High rate*	*High rate*
Extent of interdisciplinarity	Less interdisciplinair	High interdisciplinair
Growth of knowledge	*Unclear*	*Unclear*
Collaboration intensity between scientists	High rate	Low rate
Incorporation of (external) interests	*Unclear*	*Unclear*
Research planning	Less flexible	Highly flexible

Table 16: Characteristics per scientific field

As presented in table 16 “knowledge accumulation” appears in a high extent in both fields and the concept “growth of knowledge” was not recognized. Possible reasons for these outcomes are presented in the discussion. Subsequent, the appearance of the concept of “incorporation of (external) interests” was expected to be higher, more influenced and more complex in institutions that belong to new fields. However, the rate of complexity was not consistent and the extent of influence was the same for both fields. Still the amount of actors was higher in the nanotechnology institutions. Therefore, the expected outcomes of the process of incorporating cannot be confirmed.

A clarification is presented in the discussion. Consequently, this concept is not influenced by the consistent characteristics belonging to traditional and new scientific fields.

Following, the extent of influence of the four independent concepts on the extent of flexibility of research planning is discussed. The results prove that LRFs belonging to nanotechnology have a higher amount of industrial actors, a higher rate of diversity, a higher rate of interdisciplinarity and a lower collaboration intensity between scientists, which causes more flexible research planning than LRFs belonging to astrophysics. In LRFs of nanotechnology the high extent of flexibility is caused by an increase of steering actors on the LRFs. In order to collaborate with these actors and receive funding, the managers of LRFs can be pushed to adjust their selected research topics, which requires a flexible research planning (Mitchell et al., 1997). These steering actors are connected to the four independent concepts. Firstly, a higher amount of industrial actors means a higher amount of objectives from the industry. Industrial objectives are mostly specific, since they aim to develop or improve a product/process and ask an LRF to create knowledge in line with this product/process (Gibbons et al., 1994; interviewee C2). This means there is minor room to deviate, thus the LRFs are asked to decline or adapt to the demands of the industry. In order to adapt, flexibility in research planning is required. In case of a low presence of industrial actors, the research subjects can be selected with less external demands. This causes a more rigid research planning. Secondly, the rate of diversity is connected to the variety of actors with different backgrounds, as different backgrounds cause different interest (Laudel, 2006; Lepori & Reale, 2012). This causes flexible research planning, in order to deviate from the current research topics and suffice the demands. Thirdly, a high rate of interdisciplinarity points out that scientists from different disciplines collaborate (Bonaccorsi, 2008; Gibbons et al., 1994). These scientists are used to different methods, other standards and have different kinds of objectives. Thus in institutions with a higher rate of interdisciplinarity, more discussions about the selection of topics are recognized. This causes flexible research planning, since preliminary planned research will dissuade these discussions and interdisciplinary collaborations. Finally, a high extent of collaboration intensity of scientists is caused by mutual dependency. Institutions with a high rate of mutual dependency are characterized by scientists with collective goals, thus steering of these scientists is less complex. In this case there is less room needed to deviate, since most scientists are interested in the same topics. This requires less flexible research planning. In conclusion, these independent characteristics are connected to demands of steering actors and determine to what extent the research planning is flexible.

To sum up, coordination is only defined by the mode of flexibility of research planning, as the concept of incorporation gave inconsistent outcomes. This leads us to the answer of the research question; coordination of LRFs is influenced by the characteristics of the presence of university, industry and government, diversity of topics, the extent of interdisciplinarity and collaboration intensity between scientists. Where the characteristics of nanotechnology cause a flexible research planning and the characteristics of astrophysics cause a more rigid research planning.

The introduction stated that the Netherlands is not successful in coordinating their LRFs and expected that the rate of unsuccessful coordination varies per scientific field. Since coordination is conceptualized as the research planning, it can be argued that successful research planning depends on the four, earlier discussed, characteristics of an institution. Which indeed varies per scientific field. For the six investigated LRFs, this means that to adjust their mode of research planning, these characteristics need to be modified. Then the rate of successful coordination can be increased.

Discussion

In this chapter several limitations are outlined and opportunities for further research presented.

This study goes into institutions in the Netherlands, since the Netherlands was found to be unsuccessful in coordinating her LRFs. In order to identify the causes for this weak coordination policy, this study connected the characteristics of knowledge production to coordination in LRFs. This thesis was the first to take such an approach and therefore had an explanatory nature. The results created stepping stones for further research, in which more cases could be included. For example, it would be interesting to include cases from other countries, to identify the differences in coordination policies and the causes for these differences. As the Netherlands is argued to be unsuccessful in coordinating her LRFs than other countries.

Furthermore, this rate of successful coordination of the institutions is not investigated, since the aim of this study is to identify how institutions are coordinated. However, the outcomes of the study can be used to adjust coordination of institutions and as a basis for further research.

Another aspect that is subject to the scope is the amount of years that is investigated. The study goes into publication data of five years; 2008 – 2012. The concept of "growth of knowledge" is strongly dependent on the amount of years that is studied. A growth of knowledge was expected for the cases belonging to nanotechnology, through the entry of new scientists in the field and an increase of short term research projects. This aspects was measured by the amount of publications per year. As discussed in the results, the outcome of this concept fluctuates per case. A reason for the unexpected outcome could be that nanotechnology is saturated, since the field was first identified in 1974 by Taniguchi (Hughes, 2000). Probably after 1974 an enormous growth can be identified, however 40 years later the knowledge development might be more stable. Thus, in order to identify a growth, the amount of years that are investigated could be enlarged in further research. Moreover, the literature grounded this concept on publication data of whole scientific fields, including a higher amount of cases (Bonaccorsi, 2008). Therefore, it would be interesting to increase the amount of cases in further research.

The concept of "knowledge accumulation" was expected to be high in the LRFs belonging to astrophysics and low in the LRFs of nanotechnology. However, the extent is high in both fields. This can be due to the fact that LRFs are concentrated locations that study subjects using the same instruments. These instruments are extremely expensive (Roadmap, 2008), which causes that they are only purchased or created when the instruments can be used on a long period of time. The creation of knowledge in LRFs requires these instruments, thus most publications will be based on the same core of research. This elucidates the high rate of knowledge accumulation in all institutions. In the case of comparing scientific fields in general, the concentration of knowledge creation on the same instruments is not applicable. Hence, this concept was identified in the literature. To sum up, this concept cannot be used when the unit of analysis is merely LRFs.

Furthermore, this study consists of 6 cases, which are selected on basis of their turnover per year. Caused by this small sample, the outcomes of this study are not fully generalizable. However, the results provide a basis for further research, in which more cases can be investigated.

Additionally, to determine which aspects influence the coordination of LRFs in other sectors, further research can be applied in these sectors as well.

As mentioned above, the case selection was based on the turnover per year of the institutions. However some results show inconsistencies between the cases of the same scientific field. This might be explained by the case selection. As three of the six cases are located on university grounds, which means that they are strongly dependent from the university. This can be expected to influence the steering of the institution and influence the results. Therefore it is advised that further research investigates cases that are situated on similar locations.

This study investigated to what extent coordination is influenced by the dynamics of knowledge production. However, it would also be interesting to investigate the probability that coordination influences the dynamics of knowledge production as well. Considering, that the coordination of an institution is dominant and influences how research is conducted (Hessels, 2013; Lepori, 2011).

This study applied six independent concepts that determine differences in knowledge production. These concepts are derived from multiple theories, however the unit of analysis of these theories differ from this study. As the theories explained differences between scientific fields, based on whole fields. Whereas this study analyzed particular institutions that produce knowledge. Therefore, it was investigated if the concepts of these theories are also applicable to single institutions. As presented above, “knowledge accumulation” and “growth of knowledge” are not consistent throughout the cases. Consequently, they are not applicable to LRFs.

Furthermore, the concept of “presence of university, industry and government” gave some remarkable outcomes. As in three cases the interviewees pointed out that they are strongly funded through universities, which contradicts with the quantitative results. These three cases are all located on university grounds and are part of the universities. The interviewees pointed out that the universities mainly pay their basic costs, like the building and maintenance. This kind of funding is not reflected in publications, on which the quantitative results are based. The funding agencies that are included in publications are agencies that provide additional funding to conduct projects. Therefore, this quantitative indicator can be improved by investigating the revenues in the financial reports of institutions. However, due to the qualitative results the biases of the outcome of this indicator are excluded.

Subsequent, the appearance of the dependent concept of “incorporation of (external) interests” was expected to be higher, more influence and more complex in institutions that belong to new fields. The amount of actors was indeed higher in the nanotechnology institutions. However, the rate of complexity was not consistent and the extent of influence was the same for both fields. Consequently, the expected outcomes of the process of incorporating are not confirmed. An explanation might be that the managers of nanotechnology institutions are used to a higher amount of actors to incorporate and therefore do not experience any problems. Another reason can be that the steering from actors influences the institutions less than expected, caused by overlapping interests. As nanotechnology institutions are often more oriented on practical goals than astrophysics, which causes that industrial or governmental actors have objectives that are similar to these goals. In order to state that the concept of “incorporation of (external) interests” is not influenced by the dynamics of knowledge production, more research is needed, including more cases.

Another aspect that is remarkable, are the outcomes of the surveys compared to the contradicting results of the interviews and quantitative analysis. It appears that interviewees are more aware of their answers in the survey and represent their institution on a higher rate of diversity, interdisciplinarity etc. than they truly are. During the interview they talk more freely and give different statements about the same aspects. Therefore, in case of contradicting answers between the survey and other outcomes, the answers of the survey were excluded in the analysis of the results.

As mentioned, the quantitative data is collected using publication lists that were extracted from annual reports. However, not every publication was found in the Web of Science. Appendix II gives an overview of the percentage that is found per LRF. This might influence the quantitative results. However, most publications that could not be found were "telegrams" or "proceedings", which were not subject to this study. As the aim was to find articles and conference papers.

Lastly, the reliability of this thesis is ensured, since it is possible to reproduce the study and the analyses are done in a stable and objective way. It is possible to repeat the study, as the methodology clearly explains how the research is conducted. Additionally, an overview of the interview questions is provided in appendix III and the interviews are recorded. The latter provides the ability to repeat the wording of the interview, which increases the transparency of the study. Furthermore, the stability of the analysis is ensured, as the data analysis is done by one researcher, which makes the analysis stable. Also, the data is gathered and analyzed in a short period, therefore the data per concept was measured in a stable way. (Bryman, 2008). Finally, the objectivity of the analysis is ensured by taking triangulation into account. The study is conducted by applying multiple theoretical perspectives, multiple sources of data and multiple methodologies. This implies that in this study it is attempted to exclude biases of the interviewees and publication data, enlarging the objectivity.

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Appendix I

Schematic overview of the results per case

Concept	Institution A (Astro)	Institution D (Nano)
Presence of university, industry and government	Presence of public sector (high), university (moderate). Industry rate is unclear. They have social & application context objectives	Intensive collaboration with public sector, university and industry. Users are 60% from the university and 40% from the industry. Also 40% of funding is from the industry. Institution D is strongly aware that they can mean something for the Dutch society and they have application context objectives.
Diversity of topics	Low rate of diversity	High rate of diversity
Knowl. accumulation	High	High
The extent of interdisciplinarity	Low extent	High
Growth of knowledge	Some growth	High growth
Collaboration intensity between scientists	High intensity , average 39, median 7	Low intensity, average 4, median 3
Coordination - Incorporation interests	Pressure to incorporate external interest. This can be complex.	Professors decide, but are indirectly influenced by the interests of the industry and government
Coordination - Research planning	Low rate of flexibility	High rate of flexibility

Concept	Institution B (Astro)	Institution E (Nano)
Presence of university, industry and government	Intensive collaboration with the public sector and university. Industry is a supplier. Most funding is through the public sector. Institution D is social responsible. The institution does not make applications that can be used in products.	1/3 of users and funding comes from the industry. Interviewees want this to go up. 1/3 of funding through the government and 1/3 through universities. Caused by external pressures institution E is social responsible. They have application context objectives.

Diversity of topics	Low rate of diversity	High rate of diversity
Knowl. accumulation	High	High
The extent of interdisciplinarity	Moderate	High extent
Growth of knowledge	Fluctuating growth	Fluctuating growth
Collaboration intensity between scientists	High intensity, average 19, median 6	Low intensity, average 4, median 4
Coordination - Incorporation interests	Institution B does not set its own agenda. So strong influences. This is not a problem	Professors decide, but feel pressure from external parties. Incorporation of all interests can be hard
Coordination - Research planning	Low rate of flexibility	Moderate rate of flexibility

Concept	Institution C (Astro)	Institution F (Nano)
Presence of university, industry and government	Most users are from the university 54% and 45% from the public sector. No industry involvement. Institution C wants to be social responsible but is not always able to do that with their subjects. There are no application context objectives.	Intensive collaboration with the public sector (strong) and the industry. Less university involved. They have social & application context objectives
Diversity of topics	Moderate rate of diversity	High rate of diversity
Knowl. accumulation	High	High
The extent of interdisciplinarity	Monodisciplinairity	High extent
Growth of knowledge	High growth	No growth
Collaboration intensity between scientists	High intensity , average 11, median 6	Low intensity, average 4, median 3
Coordination - Incorporation interests	Some pressure to incorporate external interest. Professors decide.	Low pressure to incorporate external interest.
Coordination - Research planning	Low rate of flexibility	High rate of flexibility

Appendix II

Overview of the extent of interdisciplinarity

The extent of interdisciplinarity						
Inst.	Interview	Survey, classification & identified disci	Articles that cited	Journals that were cited	Rao-Stirling	Total extent
A	Multiple disciplines	High & 3,5	68% in first category	86% in first category	0,30	Low
B	Several disciplines	High & 3,5	76% in first category	79% in first category	0,61	Moderate
C	Two disciplines	Moderate % 3,5	88% in first category	100% in first category	0,20	Low
D	Many disciplines	High & 6	16% in first category	13% in first category	0,48	High
E	Four disciplines	High & 3,5	19% in first category	19% in first category	0,50	High
F	Multiple disciplines	High & 4	16% in first category	10% in first category	0,52	High

Statistics of data collection

	A	B	C	D	E	F
% of the collected publications	59%	81%	89%	100%	60%	75%

Appendix III

Interview questions

1. Could you tell me a bit more about your function in the institution?
2. Do you receive subsidies of the government?
    a. If so, do they expect that you contribute to social goals like the Grand Challenges?
    b. Who makes these goals?
    c. What are the consequences if you don't achieve these goals?
3. Does the industry invest as well? How many projects are done in collaboration with companies?
4. Does this institution produce applications? Or knowledge that can be used in applications?
    a. Who makes these application based goals?
    b. What are the consequences if you don't achieve these goals?

5. Who are the users of the institution?
    a. Are that scientists or also users from the industry?
6. To what extent are scientists and users from the industry collaborating?

7. To what extent does the facility management coordinate the selection of research projects?
8. If external or new projects are not in line with the current studies, are they accepted or rejected? Why?
9. How do you divide the research time of the facilities?
    a. And in case the capacity is not big enough? Does the own research teams get priorities?
    b. Is there also room for new research? If yes, is this by coincidence or preliminary decided?
10. What are the demands for new projects to get accepted?

11. How do you coordinate this institution?
12. What actors play a role, when you select research topics?
13. How do you experience this selection process?
14. To what extent are there policies in place to decide what projects are selected?

Survey questions

Name:

Function:

Years that you work at the institution:

1. Could you check the extent of collaboration between users of the industry and the institution?

Low rate of collaboration		-	high rate of collaboration		I don't know
0	0	0	0	0	0

2. Looking at the users, could you check which nationalities are presented? You can check multiple boxes.

☐ Australia	☐ Iran	☐ Russia
☐ Belgium	☐ Israel	☐ Singapore
☐ Brazil	☐ Italy	☐ Spain
☐ Canada	☐ Japan	☐ Taiwan
☐ China	☐ Malaysia	☐ Czech
☐ Denmark	☐ Netherlands	☐ USA
☐ Germany	☐ Austria	☐ South-Korea
☐ France	☐ Poland	☐ Sweden
☐ Great-Brittan	☐ Portugal	☐ Switzerland
☐ India	☐ Romania	☐ ....

3. Could you check the amount of research time that is used by foreign research groups?
☐ 0-20% ☐ 20-40% ☐ 40-60% ☐ 60-80% ☐ 80-100%

4. Could you check the which dicsiplines are represented here, through researchers? You can check multiple boxes. (derived from the UNESCO nomenclature digit-2)

☐ Logic	☐ Geoscience	☐ Sociology
☐ Math	☐ Agriculture	☐ History
☐ Astronomy	☐ Medicine	☐ Philosophy
☐ Physics	☐ Technological Sciences	☐..
☐ Chemistry	☐ Geography	
☐ Life sciences	☐ Psychology	

5. To what extent are the disciplines of question 4 divers in your institution?
Low rate of diversity - high rate of diversity I don't know
0 0 0 0 0 0

6. Do users of different scientific backgrounds collaborate? YES/NO (cross what is not applicable)
 a. If yes, could you check to what extent they collaborate?
Low rate of collaboration - high rate of collaboration I don't know
0 0 0 0 0 0

7. Could you check the extent of diversity of the topics that are researched here?
Low rate of diversity - high rate of diversity I don't know
0 0 0 0 0 0

z.o.z.

8. Could you check to what extent you expect that the diversity of subjects is influenced through the background of the users?
   Low rate of influence - high rate of influence I don't know
   0 0 0 0 0 0

9. Could you check to what extent you expect that the selection of topics is influenced by external interests?
   Low rate of influence - high rate of influence I don't know
   0 0 0 0 0 0

10. To what extent do projects are based on earlier projects?
    Low extent of knowledge accumulation – high extent of knowledge accumulation I don't know
    0 0 0 0 0 0

11. Could you check to what extent your knowledge production is growing or is stable?
    Stable knowledge production - growth of knowledge production I don't know
    0 0 0 0 0 0

Interview and survey interpretation scheme

Concept	Indicator	Question
Incorporation of external interests	Identifying external actors	IQ. 11, 12
	The rate of influence	IQ. 7, 8, 11 SQ. 8, 9
	The rate of complexity	IQ. 9, 10, 11, 13
Research planning	The flexibility of the time planning	IQ. 11, 14
Presence of university, industry and government	Collaboration between universities, industries and the government	IQ. 2, 3, 5, 6 SQ. 1
	Social context objectives	IQ. 2,
	Application context objectives	IQ. 3, 4,
Divergence topics	Rate of divergence research topics	IQ. 9 SQ. 5, 7, 8
Knowledge accumulation	Extent of knowledge accumulation	SQ. 10
The extent of interdisciplinarity	Degree of interdisciplinary	SQ. 4, 6
Growth of knowledge	Extent of knowledge growth	SQ. 11
Collaboration intensity between scientists	Collaboration intensity	
	International scientists	SQ. 2, 3