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Towards effective governance of information in a Brazilian agricultural research organisation

by

Patricia Rocha Bello Bertin

Doctoral Thesis

Submitted in partial fulfilment of the requirements

for the award of

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Abstract

There are three different uses of the term 'information' in ordinary language: in the restricted sense, it means diverse types of material objects, such as data or documents ('information-as-thing'); alternatively, the term is used as in reference to the act of informing or becoming informed ('information-as-process'), or to equate to knowledge ('information-as-knowledge'). Each of these connotations represents a legitimate view of information in its own right, being equally significant to information-intensive organisations. The literature lacks studies that approach information from an integrative viewpoint, however.

The purpose of this study was to explore and develop the notion of 'information governance' as an integrative, systemic approach to information in the context of research organisations. Soft Systems Methodology was used in a case study involving the Brazilian Agricultural Research Corporation. Qualitative data was gathered through in-depth interviews with researchers and information/knowledge managers, followed by a thematic, two-level analysis.

From a 'macro-level' of analysis (the wider Brazilian agricultural research system) it was found that, to solve increasingly complex research problems, collaborative, multidisciplinary networking is needed. On the other hand, competitive forces are continuously emanating from the systems of research steering, funds and resources' allocation, quality control, and recognition and reward. This conflict inhibits the collaborative sharing of 'information-as-thing' and '-as-knowledge', disturbs internal communication flows and contributes to low levels of synergy and cross-departmental partnerships, ultimately affecting research outcomes. At a 'meso-level' (the local practices and culture of agricultural knowledge production), different epistemic cultures were identified (named *in vitro*, *in situ* and *in silico* research), which respond differently to the opposing forces of collaboration and competition.

Based on a deep understanding of the agricultural research system and underlying epistemic cultures, a framework for effective governance of information was developed. Action to improve the governance of information at Embrapa would involve nurturing an information culture that supports collaborative work. Given that interactions between researchers are determined by their individual pursuits and struggles, this would require a change in the corporate system of performance evaluation and reward, according to the different epistemic cultures.

Keywords: information governance, information and knowledge management, epistemic culture, agricultural research, knowledge production, research system, soft systems thinking

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Finally, my deep thanks to the God almighty, who gave me strength, wisdom, and peace to pursue my dream.

Dedication

To the ones I love so deeply,

My parents Neusa and Augusto,

My husband Higor and

children Gabriele and Eduardo

For apart from inquiry, apart from the praxis, individuals cannot be truly human. Knowledge emerges only through invention and re-invention, through the restless, impatient, continuing, hopeful inquiry human beings pursue in the world, with the world, and with each other.

(Paulo Freire, Brazilian educator, in Freire, 2005, p.72)

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Abbreviations

Capes	Federal Agency of Support and Evaluation of Postgraduate Education (Brazil)
CLP	Local Publications Committee (from Embrapa's Research Units)
Cnpq	National Council for Scientific and Technological Development (Brazil)
CTI	Internal Technical Committee (from Embrapa's Research Units)
DPD	Department of Research and Development (of Embrapa)
DTT	Department of Technology Transfer (of Embrapa)
Embrapa	Brazilian Agricultural Research Corporation
GLP	Good Laboratory Practices
GMOs	Genetically Modified Organisms
GNI	Gross National Income Per Capita
ICTs	Information and Communication Technologies
IG	Information Governance
IKM	Information and Knowledge Management
IPI	Index of Institutional Performance (of Embrapa's Research Units)
IS	Information Science
ISO	International Organization for Standardization
IT	Information Technology
Labex	Embrapa's Virtual Laboratories Abroad
NCBI	National Center for Biotechnology Information (USA)
NHS	National Health Service (UK)
R&D	Research and Development
SGS	Secretariat for Management and Strategy (Embrapa)
SNPA	National Agricultural Research System (Brazil)
SSM	Soft Systems Methodology
SSS	Social Studies of Science
STS	Science and Technology Studies

Glossary

Academic Capitalism	Account by Slaughter and Leslie (1997) that demonstrates how higher education is being increasingly obligated to the extra-academic market. The authors defined 'Academic Capitalism' as the "institutional and professorial market or market-like efforts to secure external moneys" (Slaughter and Leslie, 1997, p.8).
Action research	Research that is "concerned with learning from the relationship between theory and practice and which leads to that learning that can be applied" (Wilson, 2001, p.xi).
Biome	A "large, regional ecological unit, usually defined by a dominant vegetative pattern" (Wilgen *et al.*, 2008, p.337).
Case study	The 'unit of analysis' through which one may look in-depth at a phenomenon or entity, such as one or more individuals, groups, communities, or organisations. The context to be investigated in a case study can be selected for being typical, unique, experimental, or highly successful (Merriam, 2002).
Coalition	Temporary alliance of distinct parties, for joint action, mutual assistance and protection.
Corporate governance	Refers to "the structures, process, cultures and systems that engender the successful operation of the organisations" (Keasey *et al.*, 1997, p.2).
Culture	The "beliefs, values, and attitudes that shape the behaviour of a particular group of people" (Merriam, 2002, p.8), and which has the potential of being passed on to new group members.
Cyberscience	Introduced by Nentwich (2003, p.22), the term Cyberscience encompasses "all scholarly and scientific research activities in the virtual space generated by the networked computers and by advanced information and communication technologies, in general".
Developing country	Based on the levels of Gross National Income (GNI) per capita, the World Bank (2013b) classifies national economies as low income, middle income (subdivided into lower middle and upper middle), or high income. Countries with low or middle levels of GNI are classified as 'developing countries'.
Enterprise University	General pattern observed in Australia by Marginson and Considine (2000), for making the university more like an enterprise.
Epistemic culture	Knorr-Cetina (1999) proposed the concept of 'epistemic cultures' as the relevant units of contextual organisation of science; the cultures that create and warrant knowledge. Emphasising knowledge as practice, the focus in an epistemic culture approach "is on the construction of the machineries of knowledge construction [so as to] open up the black box that constitutes scientific enquiry and make sense of the various activities observed" (Knorr-Cetina, 2007, p.363).
Epistemic objects	The scientific objects; those which are being scientifically explored

	and in the process of being developed, characteristicaly open, question-generating, complex, and perpetually incomplete (Knorr-Cetina, 2008).
Ethnography	Qualitative study that presents a sociocultural interpretation of the data, most commonly collected through direct observation. Ethnographic case studies examine the culture of a particular social group in depth (Merriam, 2002).
Ethos of science	The "affectively toned complex of values and norms which is held to be binding on the man of science" (Merton, 1973, pp.268–269).
Finalization Science	The Finalization Science account claims that all scientific disciplines follow a general development scheme that encompasses three specific stages: the explorative, the paradigmatic, and the post-paradigmatic stage. In the last phase, theory can be extended in the direction of practical applications and 'finalization' occurs. Finalization is, therefore, "the process through which external goals for science become the guidelines of the development of the scientific theory itself" (Böhme *et al.*, 1976, p.307).
Holistic property	In systems thinking, a holistic property is one that is not manifested in isolation by any of the parts of a system. For transcending the properties of the constitutive parts of the system, holistic properties scarcely can be unveiled by traditional analytic science and conventional scientific methods. In parallel, the parts have properties which are not manifested by the system as a whole (Skyttner, 2005).
In-depth interview (also 'conversational' or 'unstructured' interview)	A flexible format interview that often takes the form of 'conversations', "usually based on a question guide but where the format remains the choice of the interviewer, who can allow the interview to 'ramble' in order to get insights into the attitudes of the interviewee" (Walliman, 2006, p.215).
Information-as-knowledge	That which is perceived in 'information-as-process', which equates to knowledge (Buckland, 1991).
Information-as-process	The act of informing or becoming informed (Buckland, 1991).
Information-as-thing	Diverse types of material objects, such as data or documents, that are regarded as being informative, or "whatever information storage and retrieval systems store and retrieve" (Buckland, 1991, p.351).
Information behaviour	How "people need, seek, give and use information in different contexts" (Pettigrew, 1997, p.44).
Information culture	For Choo *et al*. (2008, p.792), information culture is "the socially shared patterns of behaviors, norms, and values that define the significance and use of information". In line with the integrative view of information that is pursued in this thesis, the term 'information culture' is adopted here in a broader sense, as in reference to 'the whole of the interactions of individuals with information — '-as-thing', '-as-process', and '-as-knowledge'

	(Buckland, 1991) — within a given organisation'.
Information literacy	The ability "to make efficient and effective use of information sources" (Julien, 2001, p.1054).
Information management	The "application of management principles to the acquisition, organization, control, dissemination and use of information relevant to the effective operation of organizations of all kinds" (Wilson, 2003, p.263).
Information Society	That in which "the production of information values and not material values will be the driving force behind the formation and development of society" (Masuda, 1983, p.29).
Interpretivism	Epistemological position that aims to reveal interpretations and meanings, due to an understanding that social reality is "the product of processes by which social actors together negotiate the meanings for actions and situations" (Blaikie, 1991, p.120).
Knowledge management	The processes of capturing, distributing, and effectively using knowledge in organisations (Davenport and Prusak, 1998).
Macro analyses	In the study of social systems, macro analyses look at large-scale social processes, patterns and trends. Social conditions at a macro-level may have causal influence on individuals at a micro-level of analysis (macro to micro social causation) (Sawyer, 2003). A drawback of macro observations is that they tend to regard abstract or too remote entities as concrete social phenomena. The challenge for the macro-theorist, therefore, is how to avoid the charge of reification (Knorr-Cetina, 1982).
Macro-properties	In this research, macro-properties are broad statements about the functioning of the wider Brazilian agricultural research system. These macro-constructions are empirically-founded, deriving from participants' own representations of the whole system of agricultural research in Brazil.
Meso analyses	In the study of social systems, meso analyses mediate between the recurrent abstraction of macro-studies and the concreteness of individuals' everyday experience and actions (i.e. the micro-level of the social reality).
Methodology	The methodology is the link between the theory and the methods employed in a scientific investigation; "a way of thinking about and studying social reality" (Strauss and Corbin, 1998, p.4).
Micro analyses	In the study of social systems, micro analyses look at the small-scale of people in face-to-face interactions. A drawback of micro analyses is that they are liable to overlook the larger forces that influence individual behaviour. The challenge for the micro-theorist, therefore, is how to avoid the charge of subjectivism or idealism (Knorr-Cetina, 1982).
Mode 2 Knowledge Production	Emergent mode of knowledge production, as proposed Gibbons *et al.* (1994), which distinguishes itself in terms of five striking features: knowledge production in the context of application, transdisciplinarity, institutional heterogeneity,

	increased social accountability and reflexivity, and new forms of quality control.
Norms	In a social system, norms are "socially expected behaviors" (Yasui, 2011, p.352).
Organic agriculture	Agricultural production system "that sustains the health of soils, ecosystems and people" (Paull, 2010, p.98).
Paradigm	In Kuhn's (1962) work, the term paradigm refers to a set of exemplars (i.e. ideas, assumptions, preconceived beliefs, methodology for gathering and analysing data) that accounts for normal scientific practice at a given moment in history, until a set of anomalies disturb that practice's paradigmatic foundation. A paradigm shift would then represent a scientific revolution.
Participatory research	In agricultural research, 'participatory research' is a configuration in which farmers become actors in the process of knowledge production.
Phenomenology	Philosophical tradition that aims to understand phenomena as they present themselves in direct experience. It assumes that there is an essence to phenomena, which results from the experiences and meanings of individuals in their actions and interactions in the social world. A phenomenological approach is, thus, "the systematic study of people's experiences and ways of viewing the world" (Backer *et al*., 2002, p.76).
Positivism	Epistemological position that values an empiricist approach to science, in which knowledge is based on systematic observation and experimentation (Walliman, 2006).
Postacademic Science	Emergent research culture that replaces academic research (traditionally accomplished at universities), as observed by Ziman (1996b). In place of the norms Communalism, Universalism, Disinterestedness and Organised Scepticism (acronym CUDOS), acknowledged by Merton (1942), Postacademic Science is Proprietary, Local, Authoritarian, Commissioned, and Expert (PLACE).
Post-normal Science	Alternative form of research that needs to emerge, so as to cope with the high levels of uncertainty and complexity of current problems of humanity and nature, as claimed by Funtowicz and Ravetz (1993). In contrast with Kuhnian 'normal science', the science appropriate for this new context should be "based on the assumptions of unpredictability, incomplete control, and a plurality of legitimate perspectives" (Funtowicz and Ravetz, 1993, p.739).
Problem situation	A real world situation of concern that is complex (usually comprised of several individual problems) and embedded in the social reality (Checkland, 1981). The problem situation can be ill-structured, semi-structured or highly-structured, depending on how easily it can be described in a concise, complete manner.
Pure basic research	Basic research that is developed without any particular application or use in view. Instead, it is curiosity-driven, "undertaken primarily to acquire new knowledge for its own sake" (Salter and Martin,

	2001, p.510).
Qualitative research	A type of research that relies "heavily on language for the interpretation of its meaning, so data collection methods tend to involve close human involvement and a creative process of theory development rather than testing" (Walliman, 2006, p.212).
Quantitative research	A type of research that relies "on collecting data that is numerically based and amenable to such analytical methods as statistical correlations, often in relation to hypothesis testing" (Walliman, 2006, p.212).
Reflexivity	"Reflection on the values implied in human aspirations and projects. The process by which individuals involved in knowledge production try to operate from the standpoint of all the actors involved" (Gibbons *et al.*, 1994, p.168).
Research data	For the purpose of this study, research data is defined as the facts that result from scientific observation, which can be recorded in lab-books, field-books, electronic databases, and so on. Research data is, therefore, a form of 'information-as-thing' (Buckland, 1991).
Research system	The whole formed by research institutes, universities, private organisations, funding agencies, and governmental bodies, among other entities, which interact in order to foster scientific development.
Rich picture	In Soft Systems Methodology (Checkland, 1981), a rich picture is a graphical representation of the issues, conflicts and any other interesting features of the problem situation under investigation.
Rural extension	An "ongoing, non-formal educational process which occurs over a period of time and [...] leads to improve the living conditions of farmers and their family members by increasing the profitability of their farming activities" (Mahaliyanaarachchi and Bandara, 2006, p.14).
Scientific communication	The set of "dynamic and complex processes, consensually and socially shared, through which scientific knowledge — in its tacit and explicit sense — is created, shared and used" (Leite and Costa, 2007, p.93 - translated from Portuguese).
Scientific information	That contained in scientific (scholarly, academic) publications in peer-reviewed journals and conferences proceedings, as well as scientific books. Scientific information is, therefore, a form of 'information-as-thing' (Buckland, 1991).
Snowball sampling	Snowballing is a sampling technique "where the researcher contacts a small number of members of the target population and gets them to introduce him/her to others" (Walliman, 2006, p.79).
Sociology of science	Sociology of science is "a specialized field of research which can be regarded as a subdivision of the sociology of knowledge, dealing as it does with the social environment of that particular kind of knowledge which springs from and returns to controlled experiment or controlled observation" (Merton, 1949, p.289).
Soft Systems	A qualitative method of inquiry on complex organisational problem

Methodology	situations through participants' self-reflection, developed by Checkland (1981).
Soft systems thinking	A strand of systems thinking that emerged as a way to inquire into real world complexity by using systems for learning (Checkland, 1981).
Strategic Research	Emerging form of research that was observed by Irvine and Martin (1984) in the UK and which came to influence policy making worldwide. Strategic Research, as defined by Irvine and Martin (1984, p.4), is "basic research carried out with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of recognized current or future practical problems".
System	In 'hard' systems thinking, systems are "mechanistic processes, with stable, or predictably varying, relationships between the relevant variables" (Crawford and Pollack, 2004, p.646). In 'soft' terms, a system may be defined as "a process of fulfilment of a purpose, or the pursuit of a goal" (Skyttner, 2005, p.390).
Systematic sampling	A sampling method that "selects samples using a numerical method, for example the selection of every tenth name on a list" (Walliman, 2006, p.215).
Systems thinking	School of thought that seeks to understand how things are "compounded and work together in integrated wholes" (Skyttner, 2005, p.V).
Thematic analysis	A foundational method for qualitative analysis that seeks to identify, analyse and report patterns (themes) within data (Braun and Clarke, 2006), and therefore can be applied across a range of epistemological and theoretical approaches.
Theory	From an interpretivist point of view, a theory is a set of meanings "which people use to make sense of their world and human behaviour within it" (Cohen *et al.*, 2011, p.8).
Triple Helix of University-Industry-Government Relations	Account of Leydesdorff and Etzkowitz (1996) that reports an increase in interactions among the institutional arenas of university, industry, and government. The Triple Helix of University-Industry-Government relations attempts to model the complex system formed by "the network overlay of communications and expectations that reshape the institutional arrangements among universities, industries, and governmental agencies" (Etzkowitz and Leydesdorff, 2000, p.109).
Tropical agriculture	Agricultural practice "between latitudes 23°N and 23°S, generally in acid, weathered, tropical soils of low fertility" (Pereira *et al.*, 2012, p.2).
Values	Values are "internal or external judgements in a [social] system to select an action for society" (Yasui, 2011, p.352).

Chapter One. INTRODUCTION

The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them.

(Sir William Bragg, quoted in Reif and Larkin, 1991, p.739)

1.1. Overview

This thesis introduces and explores the notion of 'information governance' in the context of research organisations from a systems perspective. In this chapter, the rationale and the general design of the study are explained.

The chapter commences by presenting the problem situation and the questions that motivated the study (section 1.2). The philosophical stance and the analytical framework adopted, including details of the research design and context investigated, are offered next (section 1.3). Following that, the overall aim and objectives of this study are specified (section 1.4). Its interdisciplinary nature and significance are underlined in section 1.5. The ensuing section (1.6) presents the general structure of this thesis, while the concluding one (section 1.7) provides a summary of this chapter.

1.2. The 'problem situation'

It is now widely accepted that 'information' is one of the most important assets of organisations. As with any other valuable asset, it needs to be managed efficiently so that the organisation can achieve success and be sustainable in contemporary times.

The perception of 'information' as an entity that can be measured and concretely managed, however — which is implicit in the paragraph above — represents just one of the possible connotations of the word 'information'. The ambiguity of the term has led to three different uses in ordinary language, which can be usefully distinguished as: 'information-as-thing', 'information-as-process', and 'information-as-knowledge' (Buckland, 1991). Most commonly, the word information is used in a restricted sense to mean diverse types of material objects ('information-as-thing'). Alternatively, the term is adopted in a broader sense, as in reference to the act of informing or becoming informed ('information-as-process'), or to equate to knowledge ('information-as-knowledge').

Each of these perspectives represents a legitimate view of information in its own right, being equally significant for information-intensive organisations. For those that value the construction and imparting of 'information-as-knowledge', for instance, developing conditions that support 'information-as-process' is crucial. On the other hand, the perception of 'information-as-thing' is of special interest in relation to information systems, from which perspective texts and bits are interpreted as concrete forms of information.

The notion of 'information-as-thing' has attracted considerable attention in Information Science (IS), since it is the only form of information that is tangible and therefore subject to physical manipulation or management. Developing the necessary competence for acquiring, analysing, distributing, storing, preserving, retrieving, using and controlling 'information-as-thing' is unquestionably a basic prerequisite for the success of organisations; a source of competitive advantage in a competitive market place. It is a premise of this research, however, that in the so-called Information Society[1] the competitiveness and sustainability of organisations depend greatly upon their ability to govern 'information' in the three connotations of the term.

Understanding information in such an integrative manner and developing an organisational strategy that matches this holistic perspective, however, turns out to be a complex endeavour — especially due to the intangible nature of 'information-as-process' and '-as-knowledge'. In point of fact, there is a gap in the literature in terms of studies that approach 'information' from an integrative perspective: as a rule, 'information' management, 'knowledge' management, 'data' management studies, and so forth, are treated as separate bodies of knowledge.

Research organisations provide good models for investigating the multiple facets of information in contemporary times, since 'information-as-thing', '-as-process' and

[1] Masuda (1983, p.29) defined the Information Society as a new type of human society in which "the production of information values and not material values will be the driving force behind the formation and development of society".

'-as-knowledge' represent, at the same time, crucial inputs and the main outputs of research. Nonetheless, the literature is scarce on studies that approach information issues (to encompass the three connotations of the term) from the perspective of research organisations (Chang and Li, 2007; Aurisicchio *et al.*, 2010; Correia *et al.*, 2010).

This study sets out to fill the gap in current knowledge by developing a holistic framework for research organisations to cope with 'information-as-thing', '-as-process' and '-as-knowledge', with deep consideration of the underlying research culture. This innovative approach is hereafter referred to as 'information governance' (IG)[2].

The IG framework should support the identification of systemically-desirable and culturally-feasible changes that can be implemented, so as to improve the governance of information in a research organisation. This would, in turn, facilitate the achievement of research outcomes.

It needs to be emphasised that the word 'governance', as adopted here, has a different meaning from the term 'management'. 'Governance', in the modern sense (and applied to the corporate world) refers to "the structures, process, cultures and systems that engender the successful operation of the organisations" (Keasey *et al.*, 1997, p.2). The term 'governance', therefore, is broader than 'management' and, in actual fact, encloses both a managerial and a cultural dimension[3].

The issue of IG in the context of a research organisation may well be seen as a complex 'problem situation': a real world situation of concern that is complex (usually comprised of several individual problems) and embedded in the social reality (Checkland, 1981). For organised and creative reflection on this problem situation, with consideration of underlying cultural issues, a systemic way of thinking is required.

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[2] The notion of IG, as proposed in this thesis, is further elaborated in *Chapter Two*, sections 2.4 and 2.5.
[3] While differentiating 'management' from 'governance', it is useful to think that the 'manager' is the member of governance that is responsible for executing decisions; whereas the 'governor' decides as well as determines who decides. The relationship between the information management and information governance is further explored in *Chapter Two*, section 2.4.3.

1.2.1 Research organisations as part of the wider research system

As with any organisation, research institutes do not exist in isolation. Instead, they operate within a broader context of social, political and economic structures; they influence and are influenced by the external environment, the society, other organisations and individuals. Above all, research organisations are embedded in the wider research system — jointly with other research institutes, universities, private organisations, funding agencies, and governmental bodies, among other entities — with which they interact, exchange resources and information[4].

Research systems in general, according to a growing body of literature (Böhme *et al.*, 1973; Irvine and Martin, 1984; Funtowicz and Ravetz, 1993; Gibbons *et al.*, 1994; Leydesdorff and Etzkowitz, 1996; Ziman, 1996b; Slaughter and Leslie, 1997; Marginson and Considine, 2000; Nentwich, 2003), are undergoing a significant transformation, so as to cope with the current rapidly changing, complex, and uncertain world. The notions known as 'Mode 2 knowledge production' (Gibbons *et al.*, 1994), 'Post-normal Science' (Funtowicz and Ravetz, 1993), and 'Postacademic Science' (Ziman, 1996b), to mention just a few, represent different attempts to describe and make sense of such a transformation in scientific practice.

Aspects of this transformation might have implications for the governance of information in research organisations. To appreciate this fully, a systemic approach is needed that correlates between the tensions generated in the wider context of research and the problem situation of concern. Effective IG is, at this point, a logical requirement for research organisations to be sustainable, adapt to changes and evolve in the dynamic environment of contemporary research systems.

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[4] The term 'research system' is adopted in this thesis (instead of 'science system'), to avoid the conception of 'science' as a certain, cold, straight, and autonomous activity that lacks any direct connection with the larger context of society. 'Research', instead, connotes something which is warm, involving and risky. This is also a way of acknowledging that knowledge production is not restricted to the academic realm.

1.2.2 Research questions

The questions that underpinned this research are as follows:

- Research Question 1: How can 'information governance' be conceptualised in the context of a research organisation?
- Research Question 2: How do the wider research system and the research culture influence the governance of information in a public research organisation?
- Research Question 3: How can a research organisation act to improve the governance of information?

1.3. Philosophical stance and analytical framework

Soft Systems Methodology (SSM), in its revised and more flexible form — known as Mode 2 SSM (Checkland, 1999) — comprises the main analytical framework of this study. The methodology, which is usually allied with the epistemological position of interpretivism and phenomenology, was created by Checkland (1981) as a practical framework for soft systems thinking[5].

In short, SSM comprises a qualitative method of inquiry on complex organisational problem situations through participants' self-reflection. The methodology is a form of 'action research', i.e. research that is "concerned with learning from the relationship between theory and practice and which leads to that learning that can be applied" (Wilson, 2001, p.xi). More simply, action research is research helps the practitioner, as introduced by Lewin (1946).

To look in-depth at the problem situation of interest, SSM was employed in a single case study involving the Brazilian Agricultural Research Corporation (Embrapa)[6]. Brazil's contribution to the advancement of agricultural knowledge is in great part attributable to the work of Embrapa, as part of the National Agricultural Research

[5] The research methodology and philosophical foundation of this study are detailed in *Chapter Three*.
[6] Background information to the case study is presented in *Chapter Three*, section 3.3.

System (SNPA, in Portuguese). Therefore, the choice of Embrapa as the case study context is justified for being typical (of an information-intensive organisation) and at the same time successful (in its contribution to the advancement of knowledge).

Qualitative data was gathered through in-depth interviews, followed by a thematic, two-level analysis, so as to comply with the systemic principle of this study. The 'macro-level' of analysis focused on the dynamics of the wider agricultural research system in Brazil, while the 'meso-level' examined the local practices and culture of agricultural knowledge production at Embrapa, in the context of IG.

Each systemic level of analysis has its associated theoretical underpinnings. Conceptualisations of changing research systems illuminate the analysis of the dynamics of the Brazilian agricultural research system, while the examination of the agricultural research culture at Embrapa is informed by the notion of epistemic cultures[7] developed by Knorr-Cetina (1999).

Figure 1 illustrates the rationale, the context, and the systemic, two-level analysis undertaken in this study.

[7] A review of pertinent literature and the theoretical perspective of this study are presented in *Chapter Two*.

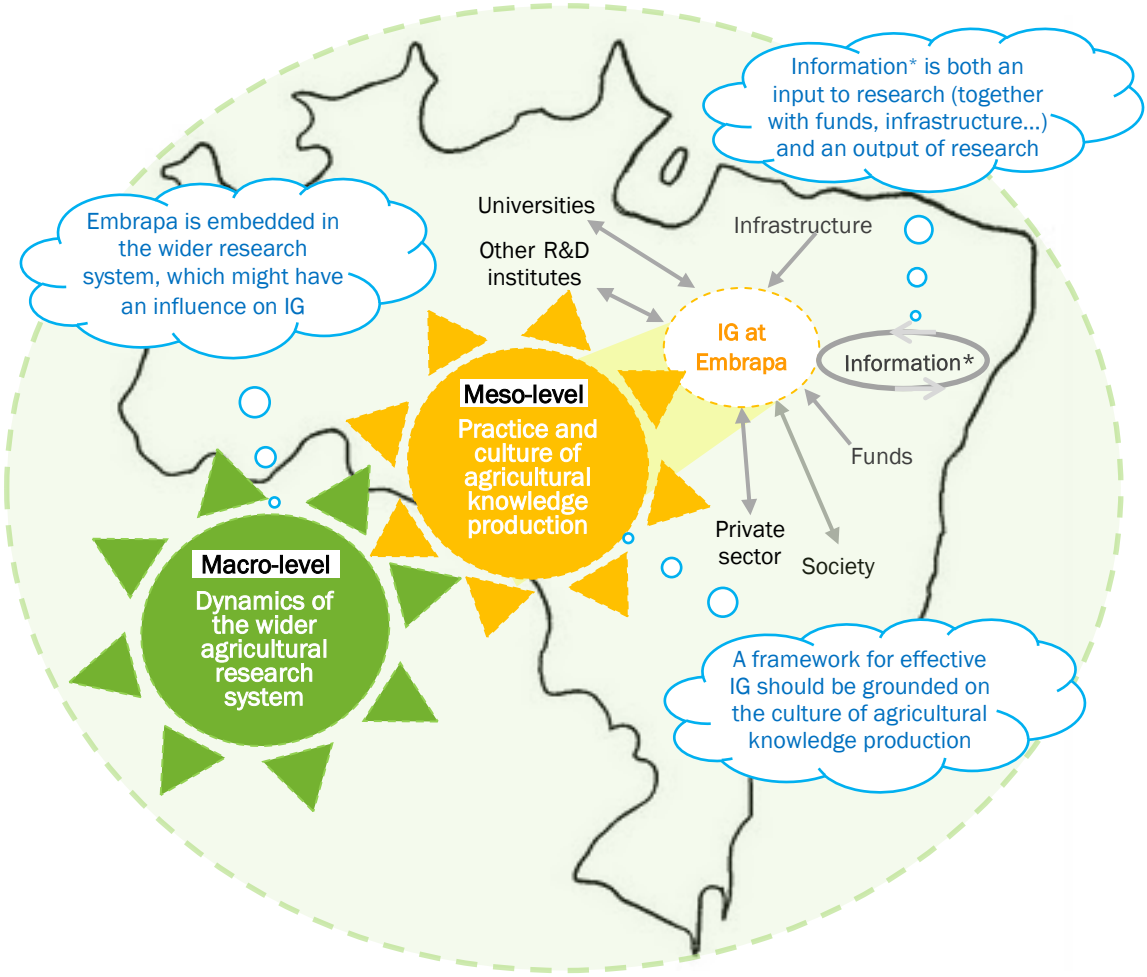


Figure 1. 'Rich picture' of the 'problem situation' (Checkland, 1981) addressed in this thesis.
*In the three connotations identified by Buckland (1991). IG: Information Governance.

1.4. Aim and objectives

The overall aim of this research was to explore and develop the notion of information governance as a holistic approach to information in the context of research organisations. To achieve the stated aim, the following objectives were devised:

- Research Objective 1: To determine the key macro-properties, the values and forces that govern the Brazilian agricultural research system, from the perspective of a public research institute.
- Research Objective 2: To explain the agricultural research culture, as perceived by researchers working in a Brazilian public institute.
- Research Objective 3: To explore the relationship between the wider agricultural research system, the local practices and culture of agricultural knowledge production, and the governance of information in a Brazilian public research institute.

- Research Objective 4: To develop an integrative, systemically and culturally-grounded framework for effective governance of information in a public research institute.
- Research Objective 5: To recommend systemically-desirable and culturally-feasible changes that can be implemented in order to improve the governance of information in a Brazilian agricultural research institute.

By 'integrative', in the fourth Research Objective, it is meant that the IG framework shall embrace the three connotations of information, i.e. 'information-as-thing', '-as-process', and '-as-knowledge' (Buckland, 1991). To be 'systemically' and 'culturally-grounded', the framework shall be developed upon a deep understanding of the functioning of the wider research system, the practices and the culture of knowledge production in concrete settings.

1.5. Interdisciplinary nature and significance of the study

This study is situated on the boundaries between Information and Knowledge Management (IKM) studies, Social Studies of Science (SSS) and Science and Technology Studies (STS), and extends current knowledge in two ways: (i) through the development of a systemically and culturally-grounded framework for effective information governance in research organisations, which is innovative and fills a lacuna in the IKM literature; and (ii) through unveiling the dynamics of a developing country research system from the perspective of a public institute, as the site of scientific knowledge production, which contributes to the STS/SSS literature.[8]

1.6. Structure of the thesis

This thesis is comprised of six chapters. *Chapter One* has presented the rationale, the aim and objectives, and the general analytical framework of this study. The next

[8] The contribution of this thesis to current knowledge is given more thorough treatment in *Chapter Six*, section 6.5.

chapter examines the body of literature to which this research is related and sets its theoretical framework (*Chapter Two*).

Chapter Three is a detailed discussion of the methodology and the research process undertaken in this thesis, including the procedures used for data gathering and analysis. The rationale for employing soft systems thinking and Soft Systems Methodology as a philosophical stance and an analytical framework is discussed. The chapter also includes relevant background information to the case study.

Chapter Four presents research findings. In line with the systemic perspective adopted, agricultural research is portrayed as a system, through which a given set of inputs are transformed into knowledge, the main output of the research activity. In *Chapter Five*, a thematic discussion of research findings is presented. The discussion culminates with the overriding theme of collaboration and competition in agricultural research, which was identified as a central factor in influencing the governance of information at Embrapa.

Chapter Six presents the conclusions of the study and explains how the original objectives have been met by research findings. A systemic and culturally-grounded framework for effective governance of information in a research organisation is offered next. The chapter then shifts to discuss the contributions of the study, in terms of the unit and scale of analysis, the context investigated, and the innovative, holistic approach to information. The appropriateness of the methodology adopted, limitations of the study and avenues for future research are presented next. The concluding section is a reflection on my personal journey in the course of this study.

1.7. Summary

This chapter has outlined what this research aims to achieve, which is: to explore and develop the notion of information governance as a holistic approach to information in the context of research organisations. An overview of the problem situation addressed, the context chosen for investigation and the interdisciplinary, systemic approach adopted in this research was presented. The significance of the study, through its contribution to current knowledge in IKM, SSS and STS was summarised. Finally, the chapter outlined the general structure of this thesis.

Chapter Two. LITERATURE REVIEW AND THEORETICAL PERSPECTIVE

One thing I have learned in a long life: that all our science, measured against reality, is primitive and childlike — and yet it is the most precious thing we have.

(Albert Einstein, quoted in Hoffmann, 1976, p.287)

2.1. Introduction

This chapter sets out the conceptual framework of this study by presenting a critical review of underpinning theoretical perspectives. Reflecting the interdisciplinary nature of the problem situation addressed in this study[9], two main bodies of knowledge were critically reviewed. The first draws from Science and Technology Studies (STS), Social Studies of Science (SSS), Sociology of Science and correlated domains, while the second, from Information and Knowledge Management (IKM) studies. The two domains are interconnected in a systems way of thinking to form the theoretical foundation of this study, as **Figure 2** shows.



Figure 2. Broad knowledge domains implicated in the problem situation of concern.
*STS: Science and Technology Studies; IKM: Information and Knowledge Management; SSS: Social Studies of Science.

The structure of this chapter is as follows. The next section (2.2) centres on the theory of science as a social institution. Following that, section 2.3 discusses the competing diagnoses of changing research systems that have emerged in the literature of the last forty years. The chapter then shifts from focusing on the changing dynamics of research systems to review the theoretical grounds upon which the notion of 'information governance' rests (section 2.4). Having reviewed the literature, the guiding set of assumptions that inform the theoretical framework of this thesis is presented in section 2.5. The final section (2.6) is a summary of this chapter.

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[9] The interdisciplinary character of this study was previously explained in *Chapter One*, section 1.5.

2.2. The social nature of science

The structure and the nature of scientific work have been investigated from a variety of standpoints, predominantly by philosophers, historians and sociologists. In this study, the perspective of science as a social institution is favoured.

Among the most influential studies about the social organisation of science are those by Robert Merton, who is often credited with having founded the sociology of science[10] (Cole, 2004; Hargens, 2004). Merton perceived science as a social institution that aims at extending certified knowledge, the ethos of which, he argued, is the "affectively toned complex of values and norms which is held to be binding on the man of science" (Merton, 1973, pp.268–269). Such values and norms were synthesised in four 'imperatives' of science in one of Merton's earliest and most seminal papers (Merton, 1942), commonly referred to by the acronym CUDOS[11]. These were: Communism (which means that substantive findings in science are socially constructed), Universalism (pre-established impersonal criteria apply to truth claims in science, whatever their source), Disinterestedness (science is not pursued for personal gain), and Organised Scepticism (judgement is reserved until scientific facts are at hand). Autonomy, empiricism and rationality were also acknowledged by Merton as important values in the 'pursuit of science', which he defined as being primarily "a disinterested search for truth and only secondarily a means of earning a livelihood" (Merton, 1973, p.323).

Merton's study of the normative structure of science was pervasive and productive in the field for a long time (Hagstrom, 1965; Storer, 1966; Cole and Cole, 1967, 1968, 1981; Gaston, 1978); not without being challenged, though. The main criticisms

[10] The sociology of science, as introduced by Merton (1949, p.289), is "a specialized field of research which can be regarded as a subdivision of the sociology of knowledge, dealing as it does with the social environment of that particular kind of knowledge which springs from and returns to controlled experiment or controlled observation".

[11] Purposefully, the acronym 'CUDOS' resembles the similar-sounding term 'kudos', which means acclaim and prestige.

included the tenuous empirical foundation of Merton's work (Mulkay, 1969) and his restrictive focus on the 'pure science' developed at the university (Barnes and Dolby, 1970). Etzkowitz and Leydesdorff (2000) pondered, however, that Merton's position in favour of a 'pure science' in the early 1900's was a response to a particular historical situation, so as to protect the free space of science.

The most recurrent, critical reaction to Merton's theory, however, was against his conception of science as an autonomous and homogeneous institution, governed by constant imperatives (Barnes and Dolby, 1970): the norms and values that governed science in the seventeenth century could not be the same in times to come. In fact, from the predominantly amateur science of the seventeenth and eighteenth centuries, up to the twenty-first professional, large-scale research systems, the way scientific knowledge is produced and the relationship between science and society have significantly changed, with no signs of achieved stability. Contemporary scientific work occurs in a wide variety of institutional settings, and new models of financial support, communication, intellectual property and technological frameworks have had an impact on the conduct of research.

In the scholarly debate, the conception of science as an autonomous and homogeneous institution — typified by the 'pure' research of the university — declined gradually (Barnes and Dolby, 1970). Much influenced by Thomas Kuhn's (1962) theory of paradigms[12], current understanding in the 'new sociology of science'[13] endorses the view of science as a dynamic, human pursuit of knowledge, with studies that embrace the specific activities, theories and concepts of the scientist in the real world.

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[12] Locating one unequivocal definition of the word 'paradigm' in Kuhn's (1962) work proves a difficult challenge, but generally he seems to refer to a set of exemplars (the set of ideas, assumptions, preconceived beliefs, methodology for gathering and analysing data) that accounts for 'normal' scientific practice at a given moment in history, until a set of anomalies disturb that practice's paradigmatic foundation. Crisis "results and persists until a new achievement redirects research and serves as a new paradigm" (Hacking, 2012, p.xxiii). A paradigm shift represents a scientific revolution.

[13] Also known as 'sociology of scientific practice' and 'sociology of scientific knowledge', the 'new sociology of science' became a central part of the larger field of science, technology, and society (Knorr-Cetina, 1991).

In the next section, the body of knowledge concerning the dynamics of research systems is critically reviewed. In common, these studies draw attention to an assumed change in the ways scientific knowledge is produced, with focus on the landscape of the highly developed economies.

2.3. Conceptualisations of changing research systems: in search of a framework for developing countries

Attempts to describe the major changes in the way scientific knowledge is produced have flourished in the literature of the last 40 years. The conceptualisations known as 'Finalization Science' (Böhme *et al.*, 1983), 'Strategic Research' (Irvine and Martin, 1984), 'Post-normal Science' (Funtowicz and Ravetz, 1993) and 'Mode 2 Knowledge Production' (Gibbons *et al.*, 1994), among others, represent different attempts to make sense and assess the wider implications of such a change in scholarship.

Having emerged in diverse places and times, the various theorisations produced an equally diverse terminology, adopting different words and concepts to refer to somewhat similar ideas. Thus, while some of them report the emergence of a new way of doing 'research', others refer to the changes in the 'science' system, or in the 'production of knowledge', with a strong focus on the role played by the university. For conveying similar ideas, however — often emphasising the increased interference of external forces in the world of science — these conceptualisations are here considered as part of the same broader body of literature.

In common, these conceptualisations were produced in the context of highly developed nations, such as the United Kingdom, United States of America, Germany and Australia. There is a lacuna in the literature when it comes to the recent developments of science in the context of developing countries. For a better understanding of the specificities of this context, the classification of national economies from the World Bank might be useful.

The World Bank classifies national economies as low income, middle income (subdivided into lower middle and upper middle), or high income, based on the levels of Gross National Income Per Capita (GNI). Therefore, a country with a GNI of $1,025 or less is considered 'low income'; $1,026 to $4,035, 'lower middle income'; $4,036

to $12,475, 'upper middle income'; and $12,476 or more, 'high income' (World Bank, 2013b). Following this definition, countries with low or middle levels of GNI are classified as 'developing countries' — even though not all economies in this group experience similar rates of development. According to the World Bank (2013a), more than 80 percent of the world's population live in developing countries, a figure that reinforces the relevance of approaching the context of developing countries in studies of Science and Technology.

The question that follows on from such an observation is: do the available conceptualisations of changing research systems provide a reasonable framework for interpreting the recent developments of science in developing countries? To answer this question, the most cited conceptualisations of changing research systems in the literature of the last 40 years were reviewed and critically analysed as suitable frameworks for developing countries' contexts. **Table 1** presents the nine most popular theorisations and the numbers of citations received by each one, as recovered by both a search in *Google Scholar* (http://scholar.google.co.uk/) and a cited reference search in the *Web of Science* (http://apps.webofknowledge.com/).

Table 1. Citations received by the main conceptualisations of changing research systems.

Concept	Reference (first publication of the concept)	No. of citations*	
		Web of Science	*Google Scholar*
Finalization Science	Böhme, G., van den Daele, W. and Krohn, W. (1973). Die finalisierung der wissenschaft. *Zeitschrift fur Soziologie*, 2 (2), p.128–144.** Böhme, G., van den Daele, W., Hohlfeld, R., Khron, W. and Schafer, W. (1983). *Finalization in Science: The Social Orientation of Scientific Progress*. London: D. Reidel Publishing Company.	75	283
Strategic Research	Irvine, J. and Martin, B. R. (1984). *Foresight in Science: Picking the Winners*. London: Frances Pinter.	190	436
Post-normal Science	Funtowicz, S. O. and Ravetz, J. R. (1993). Science for the Post-Normal Age. *Futures*, (September), p.739–755.	692	2,034
Mode 2 Knowledge Production	Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. and Trow, M. (1994). *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. London: SAGE Publications.	2,203	9,878
Postacademic Science	Ziman, J. (1996b). "Postacademic Science": constructing knowledge with networks and norms. *Science Studies*, 9 (1), p.67–80.	45	123
Triple Helix / Entrepreneurial University	Leydesdorff, L. and Etzkowitz, H. (1996). Emergence of a Triple Helix of university–industry–government relations. *Science and Public Policy*, 23 (5), p.279–286.	100	491
Academic Capitalism	Slaughter, S. and Leslie, L. L. (1997). *Academic Capitalism: Politics, Policies, and the Entrepreneurial University*. Baltimore: John Hopkins University Press.	897	1,320
Enterprise University	Marginson, S. and Considine, M. (2000). *The Enterprise University: Power, Governance and Reinvention in Australia*. Cambridge: Cambridge University Press.	223	1,218
Cyberscience	Nentwich, M. (2003). *Cyberscience: Research in the Age of the Internet*. Vienna: Austrian Academy of Sciences Press.	66	244

*As per a Web of Science and a Google Scholar search conducted in January 2014. **Since the paper was published in German and had limited dissemination, the subsequent book, published in English, was also used in the cited reference search.

The central assumptions of each analytical conceptualisation are presented in sections 2.3.1 to 2.3.8, in a chronological order of their first supporting document's publication, starting from the 'Finalization Science' account and ending with 'Cyberscience' and related conceptualisations. Final discussion is presented in section 2.3.9.

2.3.1. 'Finalization Science'

A heated debate was inaugurated in Germany in 1973, when a research group from Starnberg reported a growth in the social orientation of scientific progress (Böhme *et al.*, 1973). The authors of what became known as the 'Finalization Science' account claimed that, when a scientific discipline reaches maturity, its subsequent theoretical development is susceptible to external control (Böhme *et al.*, 1976).

The ambiguity of the notion's name — with the Latin *finis* meaning both 'aim' and 'endpoint' — and the interpretation that the authors were looking to limit the autonomy of science led to pronounced criticism, above all by the members of the *Bund Freiheit der Wissenschaft* (Association for Scientific Freedom, in German) (Pfetsch, 1979). The Finalization Science account had a strong empirical foundation, however, deriving from studies involving scientific disciplines such as physics, chemistry, and psychology.

The hypothesis of the 'Starnbergers' — as the German group of scholars became known — about the social orientations of science was developed further in a book published ten years later, in English, reaching wider audiences (Böhme *et al.*, 1983). Inspired by the work of Thomas Kuhn (1962), the basic assumption of the Finalization Science notion was that all scientific disciplines follow a general development scheme that encompasses three specific stages (Böhme *et al.*, 1973, 1983):

- the 'explorative phase', in which a scientific discipline does not have one generally accepted method neither one leading theory, and when discovery is more relevant than explanation;
- the 'paradigmatic phase', during which one theory becomes the dominant one and science develops 'autonomously', determined only by its own theoretical interest; and

- the 'post-paradigmatic phase', when the theory is mature and has proven to explain all the fundamental problems in its field and attains a kind of completeness; thus, it can now be exploited for other goals, external to science.

'Finalization' occurs in the last phase of the development of a discipline, when the theory can be extended in the direction of practical applications. In Böhme *et al.* (1976, p.307), finalization is "the process through which external goals for science become the guidelines of the development of the scientific theory itself". According to the authors, however, it is the theoretical maturing of a discipline — not any external factors — that drives it into a state in which social interferences are welcome. Thereafter, society would become an active partner in science development, defining objectives and goals of the theoretically mature discipline.

The Finalization Science account was accused by Schopman (1980, p.350) of being "too vaguely defined" and therefore difficult to use as a criterion for science policy. In the real world, Schopman (1980) argued, it is not possible to consistently distinguish between an autonomously developing science (paradigmatic science) and a science which internalises external goals (post-paradigmatic science). Instead, science policy and external goals are involved in all stages of research:

> *It seems absurd to allege that a science develops according to its own internal rules until this stage ['post-paradigmatic'], as if external goals and science policy choices were not involved at each stage. (Schopman, 1980, p.353)*

For Whitley (1984, p.3), the Finalization account reproduces Kuhn's[14] unitary view of the mature sciences and "his apparent belief that once a field became 'mature' through unspecified processes, it followed the same pattern of intellectual change

[14] Kuhn (1962) acknowledged two types of scientific activity — normal and revolutionary science. For 'Normal science', he understood that which is "firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice" (Kuhn, 1962, p.10). It is currently widely accepted, however, that revolutions are uncommon in science and that most scientific changes come through permanent discoveries, specialisation and knowledge cumulation.

regardless of its external circumstances". In this sense, there is an assumption of uniformity and inevitability in the Finalization notion that contradicts current beliefs of sciences' inherent uncertainty and variation of scientific practices. Moreover, the Finalization account focused on science as it was conducted in Germany; in the literature to date, no study could be found that appreciates the phenomenon of 'finalization' in developing countries' research systems.

2.3.2. 'Strategic Research'

Ten years after the publication of the first paper about the Finalization of Science, an alternative account of a change in the research system appeared in the UK. The term 'Strategic Research' was coined by Irvine and Martin (1984), during a policy study that came to trigger UK's Foresight Programme (Hanney *et al.*, 2001), so as to mean:

> *[...] basic research carried out with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of recognized current or future practical problems. (Irvine and Martin, 1984, p.4)*

In other words, Strategic Research is long-term, use-inspired 'basic research', i.e. basic research that goes beyond curiosity-oriented research. It is carried out not only in universities, but also in science-based firms and mission-oriented government laboratories (Martin and Irvine, 1989).

For combining relevance (to specific contexts) and excellence (towards the advancement of science), Irvine and Martin (1984) advocate that Strategic Research plays a fundamental role in socio-economic development, as there is at least some expectation that it will produce the background knowledge that is required in the development of new technologies. There is a reasonable distance, however, between the research and the eventual uptake of the knowledge that it produces. As illustrated by Rip (2002, p.125), research results "contribute to a reservoir of scientific knowledge and technological options, and others fish in the reservoir and create new combinations".

Strategic Research invites closer and more intense relationships between science and society. Nevertheless, scientists are still allowed a reasonable degree of autonomy in

setting up the research agenda and controlling the quality of research. To resolve any conflicts over priority-setting, caused by "escalating experimental costs, limited resources, complexity in scientific decision-making and pressures to achieve 'value-for-money' and socio-economic relevance" (Martin and Irvine, 1989, p.3), research foresight arises as a plausible response.

The notion of Strategic Research became influential in policy making worldwide. A number of papers can be found that refer to Strategic Research in developing countries, most commonly with a focus on research foresight (Nedeva and Georghiou, 2003; Lattre-Gasquet, 2006; Persad *et al.*, 2006; Guo, 2008; Daim *et al.*, 2009).

2.3.3. 'Post-normal Science'

Instead of describing an ongoing change in the research system — as the Finalization Science and Strategic Research accounts do — authors Funtowicz and Ravetz (1993) expressed an imperative for transformation in science. Aiming to inform science policy-making, the authors claimed that a new type of scientific activity was needed to cope with the complex, dynamic problems of natural systems, which commonly involve multifaceted interactions with humanity.

The science appropriate for this new context should be "based on the assumptions of unpredictability, incomplete control, and a plurality of legitimate perspectives", argued Funtowicz and Ravetz (1993, p.739). While prescribing the new research culture, the term 'Post-normal Science' was coined to contrast with the Kuhnian definition of 'normal science' (Kuhn, 1962). In place of value neutrality, certainty, and 'routine puzzle solving', which characterise Kuhn's 'normal science', uncertainty and values are explicit in Post-normal Science, integrating concepts of risk and the environment (Funtowicz and Ravetz, 1993). Post-normal Science is to emerge, therefore, in a context of new, enriched awareness of the functions and methods of science, where uncertainty is tackled and the scientific argument "is not a formalized deduction but an interactive dialogue" (Funtowicz and Ravetz, 1993, p.740).

Given the high uncertainties of the system and decision stakes, the issue of quality assurance is acute in Post-normal Science. To address this issue, an extended peer community scheme is necessary. An 'internal' extension of the peer community would occur through the involvement of other disciplines, whereas an 'external' extension

requires the involvement of stakeholders and public participation in environmental assessment and quality control (Funtowicz and Ravetz, 1993).

Post-normal science is issue-driven and its problem-solving activity inverts the traditional domination of 'hard facts' over 'soft values' in science. Funtowicz and Ravetz (1993) exemplify such an inversion with the problem of mitigation of the effects of sea-level rise consequent on global climate change. In a complex sequence of events, human activity is the trigger for change in the biosphere, which then leads to changes in the climatic system, and eventually to the change in the sea level. The causal chain in the observed phenomenon starts with the 'soft' human activity and research will, in the end, contribute to policy recommendations, which are 'hard' value commitments.

The main contribution of the Post-normal Science account is its acknowledgement that the scientific activity needs to change and welcome diversity, increased participation of society and reflexivity, in order to cope with uncertainty and complexity while tackling the current problems of humanity and nature. The central claim of increasing involvement of the public in research quality assurance is controversial, however, and has not been confirmed in empirical studies (Hessels *et al.*, 2009). Furthermore, the concept lacks appreciation for the context of developing countries.

2.3.4. 'Mode 2 Knowledge Production'

Among the conceptualisations of changing research systems, the account of a 'Mode 2 knowledge production' is arguably the most popular (Gibbons *et al.*, 1994). Since publication in 1994, the book 'The New Production of Knowledge' by Gibbons and colleagues has received more than 2,200 citations, as recovered by a cited reference search in the *Web of Science* (as in January 2014).

Gibbons *et al.* (1994) described the emergence of a new mode of knowledge production ('Mode 2'), which unfolds from the traditional mode ('Mode 1') and gradually establishes as prevalent. 'Mode 2' distinguishes itself in terms of five striking features: knowledge production in the context of application, transdisciplinarity, heterogeneity, increased social accountability and reflexivity, and new forms of quality control.

By research in the 'context of application', Gibbons *et al.* (1994) meant that, in the new form of knowledge production, problem formulation and solving is not set within a disciplinary framework but around practical applications, taking into account the interests of a diverse range of actors in complex social and economic contexts. To put it another way, the interests of the scientific community would no longer govern the context in which Mode 2 research problems are set and solved.

The 'transdisciplinarity' imperative of Mode 2 implies research that is based upon a common theoretical understanding, i.e. which is "accompanied by a mutual interpenetration of disciplinary epistemologies" (Gibbons *et al.*, 1994, p.29). In transdisciplinary research, a distinct framework is built, evolving from the combination of the different approaches, disciplines and specialisms involved. Yet, in accordance with the Mode 2 literature, the transdisciplinary mode of knowledge production is essentially a temporary configuration oriented towards problem solving in specific contexts of application.

'Heterogeneity' refers to the settings where Mode 2 knowledge production takes place, the composition of teams involved, and the nature of knowledge produced. While speaking of 'organisational diversity', Gibbons *et al.* (1994) argued that Mode 2 knowledge is produced not only at universities but in a diversity of settings and potential sites, through national and international cooperation and the establishment of communication networks. As a result of the interaction between a range of organisations and people with different skills and experience, authors sustain that knowledge produced in this context is more heterogeneous.

The 'reflexivity' feature of Mode 2 knowledge production is related to the levels of public awareness, interest and engagement in the scientific activity. Better educated citizenry would place new demands for research and, as different groups of society enter and become active agents in the knowledge production process, there is enhanced 'social accountability', defined by Gibbons *et al.* (1994, p.84) as the "social demand for quality, performance and value for money" in research. Researchers are more than ever sensitive to the broader implications of their activities and, in order to accommodate diverse interests, increased levels of dialogue/'reflexivity' are required. Nowotny *et al.* (2001) developed this argument further by saying that Mode 2 science evolves in the context of a Mode 2 society, which exerts strong pressure for science to

become more integrated with its social context. In this sense, Mode 2 knowledge production is socially distributed: not only does science speak to society, but society answers back to science as well. They named this process 'contextualisation' and argued that it allows the production of socially more robust knowledge. More frequent interaction with a Mode 2 society would cause research activities to transcend the context of application and reflexively engage with the consequences and impacts that research activities have on society, which Nowotny *et al.* (2001) characterised as the context of 'implication'.

A shift in the process of 'quality control' in Mode 2 knowledge production would derive from the increased social pressure for research accountability (Gibbons *et al.*, 1994). The traditional mechanism of peer-review, through which quality of research is entirely assessed by research peers for the sake of their own benefit, would be severely challenged in Mode 2. With diverse intellectual, economic, social, and political interests represented in the contexts of 'application' and 'implication', more diffuse kinds of control are involved, in order to assess the efficiency or usefulness of the solutions and the knowledge produced, which reflects the transdisciplinary nature of the problems addressed. To say it in a few words, quality control becomes more context- and use-dependent in Mode 2 knowledge production, with multiple criteria being used "in relation to the specific results produced by the particular configuration of researchers involved" (Gibbons *et al.*, 1994, p.34).

The Mode 2 idea provoked a great debate, being criticised by a number of scholars, particularly on the basis of its lack of empirical evidence, insufficient appreciation of the dynamics of society and of the articulation between 'science' and 'society', and dismissal of relevant previous literature (Tuunainen, 2005). Several works have challenged one or more of its assumptions. Gulbrandsen and Langfeldt (2004), for instance, found little support for the claims of change in the research assessment criteria; increasing convergence between university, industry, and research institutes; and emergence of new forms of assessment. Godin and Gingras (2000) found evidence that contradicts Mode 2's assertion that universities would no longer be the main locus of knowledge production. Albert (2003) disputed the claim that academic research orientation was being geared towards problem-solving, in a study that assessed the impact of pressure to develop ties with non-academic organisations in two relatively autonomous fields of research (sociology and economics).

For Weingart (1997), the Mode 2 notion is no more than a revisitation of the Finalization Science account — a priority that Gibbons *et al.* (1994) failed to acknowledge. Furthermore, he argued that Mode 2's framework cannot be generalised to science as a whole:

> *The features observed can hardly be generalized, and there are no systematic reasons in sight which would make one believe that this mode should extend to all other areas of science.* (Weingart, 1997, p.600)

Etzkowitz and Leydesdorff (2000, p.116) went further and stated that the characteristics of Mode 2 are not as recent as Gibbons *et al.* (1994) suggest, but "the original format of science before its academic institutionalization in the 19th century", while 'Mode 1' is a construct built in order to justify autonomy for science, carving out an independent space for science in its earlier era. Other studies contesting aspects of the Mode 2 conceptualisation are: Godin (1998); Shinn (1999, 2002); Martin and Etzkowitz (2000); Pestre (2000, 2003); Rip (2002); Ferlie and Wood (2003); Martin (2003); and Morton (2005).

On the other hand, several studies have empirically verified the occurrence and growth of Mode 2 knowledge production in a variety of settings and disciplines, offering support for one or more of its claimed features. The thesis of diversification of the loci of scientific production, for instance, has been attested in a couple of works (Godin *et al.* 1995; Hicks and Katz, 1996). Other works supporting one or more aspects of the Mode 2 conceptualisation are: Pettigrew (1997); Huff (2000); Harvey *et al.* (2002); Hemlin and Rasmussen (2006); and Porter and Rafols (2009).

Both supporting and discounting criticisms of the Mode 2 notion, however, tend to focus on the research landscapes of the highly advanced Science and Technology nations as their main context of analysis. There is a lacuna in research into the dynamics of science in developing economies in light of the Mode 2 notion, and studies that do exist are primarily concerned with universities, as the principal locus of knowledge production. Jansen (2002), for instance, found that the accommodation of Mode 2 characteristics within the institutional programmes of South African universities is still small and variable: most historically black universities hardly express any kind of recognisable Mode 2 characteristics. For Jansen (2002), the conceptualisation underestimates the complex organisational and cultural

arrangements, the power and status of disciplinary science at most universities in South Africa.

Another example comes from an evaluation of university entrepreneurship in Chile. Bernasconi (2005) found that, while in the industrialised world, higher education entrepreneurship may be associated with the emergence of Mode 2, entrepreneurial universities in the context of developing countries may be just finding their way into the "academic, 'Mode 1' type of research, as expressed in scholarly publications, not in patents or profits" (Bernasconi 2005, p.270). In China, conversely, Hong (2006) attested that Mode 2 scientific research is already in place, with universities' scientists actively responding to questions raised by industry. It follows that the dynamics of research systems might indeed be context-specific, even within the developing world.

2.3.5. 'Postacademic Science'

In 1996, British physicist John Michael Ziman, while contributing to the Science Policy Support Group, reported a change in the relationship between science and society. Ziman (1996b) asserted that 'academic science' — traditionally accomplished at universities — was being replaced by a new research culture, which he named 'Postacademic Science' (or 'Post-industrial Science').

In place of the imperatives of Communalism, Universalism, Disinterestedness and Organised Scepticism (acronym 'CUDOS') proposed by Merton (1942), a new set of norms characterises Postacademic Science. Ziman (1996b) named them: Proprietary, Local, Authoritarian, Commissioned, and Expert ('PLACE'). That is to say that:

> *[Postacademic Science] produces proprietary knowledge that is not necessarily made public. It is focused on local technical problems rather than on general understanding. Industrial researchers act under managerial authority rather than as individual. Their research is commissioned to achieve practical goals, rather than undertaken in the pursuit of knowledge. They are employed as expert problem solvers, rather than for their personal creativity. (Ziman, 2000, pp.78-79)*

For Ziman (2000, p.67), Postacademic Science is "a radical, irreversible, worldwide transformation in the way science is organized, managed and performed" As researchers are funded by (and effectively working for) private corporations, utility

and profitability are more than ever emphasised. In consequence, Postacademic scientists work together on problems they have not posed personally and are rewarded according to their contribution to the success of their team. What's more, an imperative for accountability of research would cause Postacademic Science to "distrust the elitism of peer-review and replace or bolster it with quality control of people, projects and performance" (Ziman, 1996a, p.753). The more collective characteristic of the scientific activity, the exponential growth of scientific activities, and the strengthened competition for resources were also indicated by Ziman (1996) as additional evidence of the emergent Postacademic Science.

It is noteworthy that Ziman (1996) does consider elements of the Finalization Science, Post-normal Science and Mode 2 conceptualisations, in his attempt to delineate the Postacademic Science. Instead of adopting any of the previous terms ascribed to the new research culture, however, Ziman (1998, p.1814) calls it Postacademic to "show that it outwardly preserves many academic practices and is still partially located in "academia"". No major contradictions seem to really exist, however, between the Mode 2 knowledge production and the Postacademic Science notions, for instance. Like Mode 2, the Postacademic Science account lacks empirical foundation and appreciation of developing countries' research contexts.

2.3.6. 'Triple Helix of University-Industry-Government Relations'

Leydesdorff and Etzkowitz (1996) reported an increase in interactions among the institutional arenas of university, industry, and government. The stronger connection between these traditionally autonomous institutions was attested through the emergence of new structures within each of them (e.g. centres and hybrid organisations in universities, such as incubator facilities), and of more prominent strategic alliances among firms, government laboratories, and academic research groups (Leydesdorff and Etzkowitz, 1996). The ''Triple Helix of University-Industry-Government relations', thus, represents an attempt to model this complex system in its social context:

> *We focus on the network overlay of communications and expectations that reshape the institutional arrangements among universities, industries, and governmental agencies. (Etzkowitz and Leydesdorff, 2000, p.109)*

For the authors of the Triple Helix model, the worldwide phenomenon of university-based incubation, assisting the growth of spin-off firms, is indicative of a major change in the nature of the academic work. In an increasingly knowledge-based society, an 'Entrepreneurial University' emerges at the core of the dynamic 'triad' of innovation as an irresistible, unavoidable development — "an internal dynamic working itself out" (Etzkowitz, 2002, p.121). Replacing the linear model of utilisation of scientific knowledge, the Triple Helix is characterised by "new organisational mechanisms that integrate market pull and technology push" (Hessels and Van Lente, 2008, p.747). **Figure 3** illustrates the overlapping of institutional spheres that characterise the knowledge infrastructure generated by the Triple Helix: each sphere taking the role of the other and hybrid organizations emerging at the interfaces (Etzkowitz and Leydesdorff, 2000).

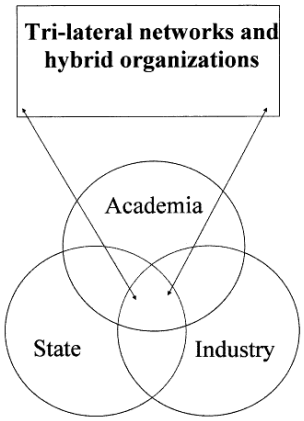


Figure 3. Triple Helix of university–industry–government relations. (source: Etzkowitz and Leydesdorff, 2000, p.111)

It is worth mentioning that the Triple Helix conceptualisation emerged gradually, with numerous interlocking pieces composing its textual architecture, such as introductions and conclusions of collective works, chapters, articles or conference papers (Shinn, 2002). In the Triple Helix community, special attention has being given to case studies in different US universities, such as Stanford and MIT (Tuunainen, 2005).

Supporting the Triple Helix account, empirical studies have demonstrated the proliferation of university-industry collaboration relations in some high-technology fields, such as biotechnology (Blumenthal *et al.*, 1986a, 1986b; Curry and Kenney, 1990; Krimsky *et al.*, 1991). Conversely, from the perspective of Albert (2003, p.178), the relative autonomy of the humanities and social sciences, as well as

"the multifarious nature of academic research, challenge such too-inclusive explanatory models", referring to Mode 2 and the Entrepreneurial University notions. Looking at a more specific context, Deem and Johnson (2003) contended that the individual and organisational behaviours implicated in the Entrepreneurial University may be atypical within the UK, since only a minority of academics, sciences and universities have become active entrepreneurs.

The appropriateness of the Triple Helix framework for the context of developing countries has been discussed in a few empirical studies. Goktepe (2003), for instance, recommended the creation of a common culture for innovation in Turkey, founded on the Triple Helix conceptualisation. In addition, Razak and Saad (2007) used a case study approach to examine the role of the Malaysian universities and their social relationships with government and industry in the light of the Triple Helix model. They found that the government was invariably the dominant actor in these relationships and that a cultural change was necessary, within the university, so that a more dynamic model of the Triple Helix could evolve. In China, on the other hand, Leydesdorff and Guoping (2001) reported that a new innovation system had been emerging since 1992, in terms of university-industry-government relations.

2.3.7. 'Academic Capitalism' and 'Enterprise University'

Slaughter and Leslie (1997) acknowledged the growth of market-like activities at universities of four English speaking countries (Australia, Canada, UK, and USA) between the 1970's and the 1990's. Their book entitled 'Academic Capitalism: Politics, Policies, and the Entrepreneurial University', published in 1997, presents several sets of statistics and policy research through which the authors demonstrate that higher education was being increasingly obligated to the extra-academic market (Slaughter and Leslie, 1997). With research becoming less curiosity-driven and more market-driven, the authors coined the term 'Academic Capitalism' as the "institutional and professorial market or market-like efforts to secure external moneys" (Slaughter and Leslie, 1997, p.8).

The increasing competition for funding was highlighted by Slaughter and Leslie (1997) as evidence of 'market-like activities' within universities, whether these funds are from external grants and contracts (e.g. endowment funds, university-industry partnerships,

or institutional investment in professors' spin-off companies), or from student tuition and fees. Correspondingly, the authors also distinguished 'market behaviours' within universities, defined as all the for-profit activities that have been encouraged by these institutions, such as: patenting, royalty, and licensing agreements, creation of spin-off companies, and university-industry partnerships, when these have a profit component (Slaughter and Leslie, 1997).

According to Slaughter and Leslie (1997), Academic Capitalism flourished as the public support for education declined and as private interest in new products and processes began to meet the needs of universities for research funding. As a means of stimulating economic growth and diversifying the sources of research funding, governments would support Academic Capitalism. The authors argued, however, that different disciplines are in varying positions regarding their ability to take advantage of the Academic Capitalism. Scientific fields that are closest to the market, such as biotechnology, take greater advantage in this respect than humanities, for instance (Slaughter and Leslie, 1997).

An analogous conceptualisation was developed by Marginson and Considine (2000), named 'Enterprise University'. Examining 17 Australian universities, they concluded that there is a general pattern for making the university more like an enterprise. Focusing on university governance issues, the book 'The Enterprise University: Power, Governance and Reinvention in Australia' gives evidence of a strict alignment between the current top-down management models to which universities are being subjected to, and the changes in the global economy and the national higher education policy (Marginson and Considine, 2000).

Among the major changes that characterise the 'Enterprise University', the authors underlined: the strong executive control of the university; the distinct character of the university mission and governing bodies emphasising marketing activities; the replacement of collegial decision-making bodies with new managerial structures that make use of incentives; the quality control and accountability from the private sector; the culture of economic consumption (expressed through university-student, university-industry or university-government relations); and the increased openness to outside funding and competition (Marginson and Considine, 2000).

Similarly to the Academic Capitalism approach, the Enterprise University notion does not proclaim the changes in scholarship as a universal and uniform development. Old established universities and the newest or less traditional universities are influenced in a variety of different ways and internal variances across scientific fields are acknowledged (Marginson and Considine, 2000).

The Academic Capitalism and Enterprise University accounts show special concern with the administrative and political issues of the academy, in contrast to the Mode 2 and the Triple Helix conceptualisations, which focus on scientific practice, per se. Also, the Academic Capitalism account concentrates on fewer features of the contemporary university activities than the Mode 2 and Triple Helix notions, particularly on the growing dependence of academics on external, competitive funds (Tuunainen, 2005).

As said before, the Academic Capitalism and the Enterprise University notions have strong empirical basis, with studies that were conducted in Australian, Canadian, British and American universities. However, the literature still lacks empirical validation of the described phenomenon in the context of developing countries. Besides, since the Enterprise University approach is deeply focused in the common patterns of change in universities' governance, it is inapplicable beyond the academic realm.

2.3.8. 'Cyberscience' and related conceptualisations

The new ICTs have enabled modern, imaginative forms of scholarship. Researchers are having unprecedented opportunities for interaction and collaboration with peers, regardless of geographical distance. Accessing the literature, sharing datasets, and disseminating research results have been dramatically facilitated by means of high-performance computational resources.

The research culture deriving from this context differs from that of the 20th century in important ways, having been described under designations such as 'Cyberscience' (Nentwich, 2003), 'e-Science' (Research Councils UK, 2010), and 'Digital Scholarship' (Borgman, 2007). Depending on the geographical area, the terms 'Cyberinfrastructure' (Atkins *et al.*, 2003) and 'e-Research' (Meyer and Schroeder, 2009) are also adopted with basically the same meaning — as in reference to the technological infrastructure that enables innovative, distributed and collaborative forms of research.

The United Kingdom was among the first nations to make specific investments in building an infrastructure for information-intensive research: the e-Science Core Program of the Research Councils of the UK began in 2001 (Borgman, 2007). The term 'e-Science' was introduced to denote the "systematic development of research methods that exploit advanced computational thinking" (Research Councils UK, 2010). Such methods enable a new mode of research by giving access to resources held on widely-dispersed locations, including data collections, scientific instruments and high performance visualisation. In brief, therefore, e-science combines three different developments: "the sharing of computational resources, distributed access to massive datasets, and the use of digital platforms for collaboration and communication" (Wouters, 2004, p.2).

The term 'Cyberinfrastructure', alternatively, is primarily rooted in initiatives based in the United States. The notion was launched by the National Science Foundation in 2003, in what has become known as the Atkins Report (Atkins *et al.*, 2003). According to the report, Cyberinfrastructure "refers to infrastructure based upon distributed computer, information and communication technology" (Atkins *et al.*, 2003, p.5). Another common term is 'e-Research', which has been defined as "the use of digital tools and data for the distributed and collaborative production of knowledge" (Meyer and Schroeder, 2009, p.247). The term e-Research is being increasingly adopted within Europe and the UK, for being more reflective of the work of both social and humanities scientists (Jankowski, 2007).

Nentwich (2003) coined the term 'Cyberscience' to capture the idea that applications and services based on the new ICTs are having an impact on a variety of constitutive aspects of the academia, particularly scientific communication, production and distribution of knowledge. Before the advent of the Cyberscience tools, remote collaboration was difficult and inefficient; nowadays, the infrastructure for collaborative work is largely viable as well as absolutely essential.

The notion of Cyberscience relates to the scientific activities developed in a new kind of space — "the virtual space created by electronic networks", or 'cyberspace' (Gresham, 1994, p.37) — such as remote information retrieval, virtual seminars and conferences, distance co-operation and extended research groups, virtual institutes

and collaboratories, and the Internet itself as a new research tool. In Nentwich's (2003, p.22) words, Cyberscience comprises:

> *all scholarly and scientific research activities in the virtual space generated by the networked computers and by advanced information and communication technologies, in general.*

The most visible impact of the emergence of Cyberscience would relate to the scientific publication system. Physical libraries start to lose ground as a gradual shift to the cyberspace takes place (Nentwich, 2003). Electronic journals flourish and the online publication of all sorts of non-reviewed material begins to challenge traditional mechanisms of scientific quality control, i.e. the peer-based scientific communication model. In this regard, Nentwich (2005, p.191) states that "traditional refereeing will be transformed and reformed along the path into the age of Cyberscience". Written discourse, however, would gain ground as Cyberscience becomes prevalent, with voice being just another interface, as new technologies would enable speech-to-text conversion (Nentwich, 2003). Aspects related to the evolution of scientific communication in the electronic age are underlined in the next subsection.

2.3.8.1. From the print to the electronic model of scientific communication

Scientific knowledge production and scientific communication are intimately related processes. The dissemination of research outputs in formal communication channels is arguably the most important process of legitimisation of science: since knowledge is intangible and difficult to assess, scientific publication records have traditionally been used as an indirect measure of knowledge production, serving as a support for the merit and reward system of scientists working in higher education (Hurd, 2000).

For Garvey and Griffith (1979), the communication of scientific knowledge is a complex phenomenon with singularities which range from the most incipient stage of scientific research — the identification of the problem to be studied — to the moment knowledge is internalised by other scientists. Leite and Costa (2007, p.93 - translated from Portuguese) defined 'scientific communication' as:

> *the set of dynamic and complex processes, consensually and socially shared, through which scientific knowledge — in its tacit and explicit sense — is created, shared and used.*

Such procedures provide the means and conditions for social interaction among scientists. Besides diffusing research results to scientific community, guaranteeing the quality and providing legitimacy through peer-review, scientific communication serves the purpose of recording the authorship and ensuring public acknowledgement and property rights of scientific findings (Leite and Costa, 2007).

For a long time, the refereed scientific article represented the central unit of the scientific communication process: formal and informal communication would eventually lead to journal publication as the expected outcome of scientific research (Hurd, 2000). Since the beginning of the 1990's, however, emerging ICTs — particularly the World Wide Web — have challenged the traditional mode of scientific communication through enhancing the possibilities of formal and informal exchanges among scientists and enabling a 'paperless' communication model, as envisioned by Lancaster (1978).

As information technology developed sufficiently enough to allow the emergence of the electronic journal as a feasible alternative — reducing the speed and the cost of publication, while increasing the possibilities of interaction and distribution — the ways scientists used, produced and disseminated information have changed. Current claims are that the traditional print-based system of scientific communication is undergoing "a transformation to a system much more reliant on electronic communication and storage media" (Hurd, 2000, p.1279). Drawing upon the estimated impact of the new ICTs, Hurd (1996) proposed a model for scientific communication that flows entirely in the electronic media (**Figure 4**). Hurd's (1996) model of scientific communication draws attention to the growth of informal communication between scientists, through the use of electronic mail and listserv discussions.

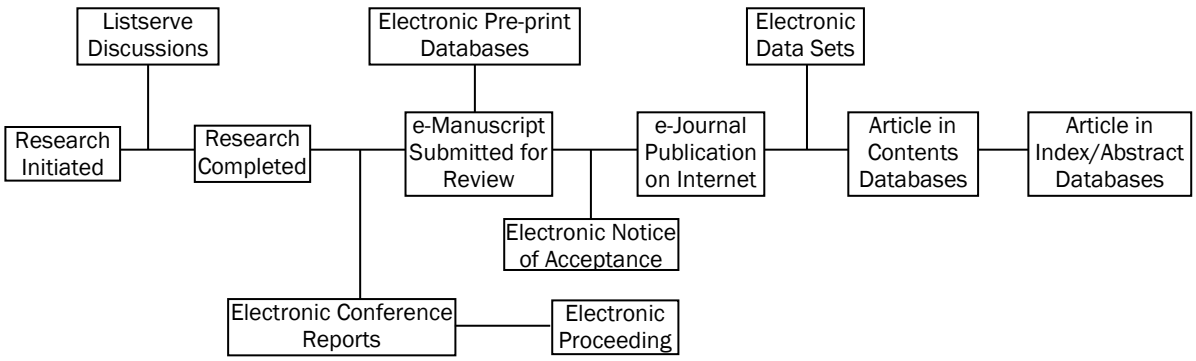


Figure 4. Scientific communication model in the electronic era. (source: Hurd, 1996, p.22)

In a subsequent work, Hurd (2000) acknowledged that discipline-specific variations are expected in the patterns of scientific communication. The importance of preprints or the speed of the transformation from the print to the electronic system of communication, for example, might vary considerably between scientific fields. Other discipline-specific aspects, such as the value placed on rapid dissemination of findings, the prevalence of large-scale collaborative projects, and the geographical dispersion of teams might affect the speed of the transformation from the print to the electronic model of scientific communication.

A reaction against the philosophy underpinning the traditional system of scientific communication has accompanied the transition to a digital culture of publication. The pricing crisis, attributable to tight library budgets and ever-increasing journal subscription costs, was one of the main factors in the rise of what became known as the 'Open Access' movement (Velterop, 2005). Its philosophy argues against the traditional publishing model in which scientific publishers hold copyrights and impose barriers to distribution and access to scientific knowledge. In short, the movement endorses the principle of shared and equitable distribution of knowledge: scientific information might be digital, online, and free of charge, copyright and licensing restrictions.

The concept of Open Access was first properly defined in 2001, at a meeting that took place in Budapest, promoted by the Open Society Institute, of a group of Open Access activists (even though at the time they did not all use the term 'open access'). Out of that meeting came the so-called Budapest Open Access Initiative, in which Open Access was defined as follows:

> *By 'open access' to this literature, we mean its free availability on the public internet, permitting any users to read, download, copy, distribute, print, search, or link to the full texts of these articles, crawl them for indexing, pass them as data to software, or use them for any other lawful purpose, without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. The only constraint on reproduction and distribution, and the only role for copyright in this domain, should be to give authors control over the integrity of their work and the right to be properly acknowledged and cited. (Velterop, 2005, p.4)*

The new worldwide paradigm of Open Access to scientific knowledge appeared as a suitable alternative for scientific information management as well as a new communication philosophy. From the Budapest Open Access Initiative, two basic strategies were established in order to make research articles freely available on the Internet: the self-archiving (Green Road), which means the deposit by authors of refereed journal articles in open electronic archives; and the instigation of a new generation of journals committed to Open Access and the assistance to existing journals that elect to make the transition to Open Access (Gold Road). Besides proposing strategies to guarantee open access to scientific information, practical tools and electronic systems have been produced to support the needs of scientific information management in a digital environment (identifying, capturing, storing, organising, digitally preserving and, principally, widely disseminating information).

The Open Archives Initiative, which has its roots in the Open Access and institutional repository movements, has set the interoperability standards for efficient dissemination of digital contents (Luce, 2001). These standards have facilitated the development of interoperable, long-term systems for storing, preserving, and searching of archives metadata. Now largely adopted by global scientific community, these systems accompany formal guidelines and policies for documents' submission and self-archiving by authors.

2.3.9. Studies of science from a 'macro' and a 'micro' perspective

Each of the conceptualisations presented in the previous sections (2.3.1 to 2.3.8) captures relevant, general aspects of the claimed transformation in the research system. Despite using dissimilar terminology, their claims converge to the emergence of more open systems of knowledge production. For focusing on general developments or system-wide properties of the research activity, these conceptualisations can be typified as 'macro analyses' of science (Knorr-Cetina, 1981).

The macro analyses discussed in this chapter are strongly orientated towards research policy-making. Accounts such as the Enterprise University (Marginson and Considine, 2000), Academic Capitalism (Slaughter and Leslie, 1997), Finalization Science (Böhme *et al.*, 1976), and Post-normal Science (Funtowicz and Ravetz, 1993) are

clearly concerned with providing research policy recommendations, while the Postacademic Science notion, for instance, came from within a national research policy group (Ziman, 1996b). The very concept of 'research foresight', which is now widely used by policy-makers round the world, was first developed by the authors of the Strategic Research notion (Rip, 2002a; Martin, 2010).

The fact that the several conceptualisations are policy-oriented raises questions about the partiality of their claims, since this type of research is often commissioned and funded by the body interested in the policy in question (Lacey, 1996). Moreover, as much of policy-oriented research, they are usually narrow in focus and yet subjected to broad application (Massagli and McCullough, 1979). The scholarly significance of these conceptualisations, therefore, can be seen as subservient to their practical use.

Another important critique of studies of science from a macro perspective is that they tend to assume a theoretical stance, rather than an empirical one — this being the case with the Mode 2 (Gibbons *et al.*, 1994) and the Post-normal Science (Funtowicz and Ravetz, 1993) accounts, for instance. Furthermore, macro analyses of science are liable to conceal or overlook significant specificities and internal variances within and across different knowledge domains. Apart from Academic Capitalism and Enterprise University, all other conceptualisations adopt a 'unitary' view of science. The changes in the research system, however, are hardly expected to occur evenly across different scientific fields, as Barnes and Dolby (1970, p.8) noted:

> *Scientific reception systems, communication patterns and property rights have varied both temporally and between different scientific sub-groups — and so accordingly have corresponding normative patterns.*

Also, the claimed changes in the research system might not be applicable to different social and political contexts. The context of developing countries, for instance, is very dissimilar from that in which the conceptualisations of changing research systems have been produced. Owing to infrastructure issues, financial, institutional and human resources' constraints, the claimed transformation of the research system might have followed different trajectories in the developing world. Nonetheless, few studies could be found in the literature that analyse the recent evolution of research systems in the context of developing countries — particularly from Latin America.

A similar gap in the literature was noted by Prpić (2007), in relation to 'transitional' (post-communist) countries of Central and Eastern Europe. Prpić (2007) came to conclude that Postacademic Science, Mode 2, Triple Helix, and Academic Capitalism were inappropriate for interpreting the dynamics of transitional research systems, due to the insufficient theoretical elaboration of these notions, the rigid demarcation between the traditional and the new mode of scientific production, and the diverging context in which the changes in knowledge production were identified: the most developed countries with "powerful economies and technological and scientific potential, massive investments in R&D and competitive research systems" (Prpić, 2007, p.488).

An important question surfaces from the considerations above, which follows: if research systems behave differently across scientific fields and broader contexts, what then are the relevant organisational units of scientists, so that one can investigate their dynamics?

Both sociologists of science and information scientists have shown an interest in determining the relevant units of differentiation of knowledge. The first group is mainly concerned with the influence of social settings and elements on the production of knowledge, while the second, with patterns of scientific communication and citations.

The wide literature investigating specific sets of peers within the knowledge world, through quantitative or qualitative methods, have adopted diverse terms such as 'scientific communities', 'research communities', 'academic communities', 'disciplinary communities', 'specialist/specialty communities', 'scientific groups', 'scientific clusters', 'knowledge communities', 'professional membership groups', among others (Lievrouw *et al.*, 1987; Raan, 1996; Costa and Meadows, 2000; Rojo and Gómez, 2006). 'Scholarly communities' — here used to encompass all other designations — are still regarded as the relevant units of organisation in science in the common sense. The community would consist of the practitioners of a specialty, identified in different categories, in accordance to the division of knowledge (scientists, social scientists, humanists), professional group (chemists, biologists, librarians), and subdivisions (organic chemists, high-energy physicists, econometricians) (Costa, 1999). Terminological issues aside, one of the features of a scholarly community is that it exhibits an identifiable 'culture', that is:

> *a set of mental constructs that may serve to guide or justify conduct between people, and to tell them how to use things. Culture defines the way the world is and how people are (beliefs), and how people and the world should be (values). (Bailey, 1992, p.1777)*

An influential study on the cultural aspects of scholarship was produced by Becher (1994), who found interrelationships between the nature of knowledge produced (cognitive aspects) and the culture of broad disciplinary groupings. Drawing from an eight-year study of research norms and practices in twelve disciplinary fields (biology, chemistry, economics, engineering, geography, history, law, mathematics, modern languages, pharmacy, physics and sociology), Becher (1987) proposed a categorisation of knowledge communities according to four broad disciplinary cultures, as **Table 2** shows.

Table 2. Nature of knowledge and culture, by disciplinary grouping. (source: Becher, 1987, p.289)

Disciplinary grouping	Nature of knowledge	Nature of disciplinary culture
Pure sciences (e.g. physics) "hard-pure"	Cumulative; atomistic (crystalline/tree-like); concerned with universals, quantities, simplification; resulting in discovery/explanation	Competitive, gregarious; politically well-organized; high publication rate; task-oriented
Humanities (e.g. history) and pure social sciences (e.g. anthropology) "soft-pure"	Reiterative; holistic (organic/river-like); concerned with particulars, qualities, complication; resulting in understanding/interpretation	Individualistic, pluralistic; loosely structured; low publication rate; person-oriented
Technologies (e.g. mechanical engineering) "hard-applied"	Purposive; pragmatic (know-how via hard knowledge); concerned with mastery of physical environment; resulting in products/techniques	Entrepreneurial, cosmopolitan; dominated by professional values; patents substitutable for publications; role oriented
Applied social sciences (e.g. education) "soft-applied"	Functional; utilitarian (know-how via soft knowledge); concerned with enhancement of [semi-] professional practice; resulting in protocols/procedures	Outward-looking; uncertain in status; dominated by intellectual fashions; publication rates reduced by consultancies; power-oriented

Although agreeing that "much can be learned from investigating the clusters of scientists", Knorr-Cetina (1982, pp.102–103) questioned the relevance of the notions of scholarly communities, disciplines, or disciplinary groupings as the significant units within which science is socially and technically organised. In her opinion, these groupings neglect one important aspect of the scientific activity: the relevant, empirically observable relationships between scientists and non-specialists. Alternatively, Knorr-Cetina (1999) proposed the concept of 'epistemic cultures' as the relevant units of contextual organisation of science, or the cultures that create and warrant knowledge — which are a structural feature of the Knowledge Society.

Knorr-Cetina's view of the Knowledge Society, however, surpasses the notion of a society where knowledge and technology performs a crucial role. More importantly, the Knowledge Society is a society that is permeated with 'knowledge settings': the "whole sets of arrangements, processes and principles that serve knowledge and unfold with its articulation" (Knorr-Cetina, 2007, pp.361–362). In this sense, epistemic cultures can be also defined as the cultures of knowledge settings:

> *It refers to those sets of practices, arrangements and mechanisms bound together by necessity, affinity and historical coincidence that, in a given area of professional expertise, make up how we know what we know. (Knorr-Cetina, 2007, p.363)*

Focusing her studies "not in the construction of knowledge but in the construction of the machineries of knowledge construction", Knorr-Cetina (1999, p.3) locates the laboratory as an essential part of the knowledge machineries of contemporary sciences. Rather than a new field of exploration or a site where experiments are performed, laboratories are reconfigurations of natural and social orders: they "recast objects of investigation by inserting them into new temporal and territorial regimes" (Knorr-Cetina, 1999, p.43). Besides creating reconfigured, workable objects, laboratories also "install reconfigured scientists who become workable (feasible) in relation to these objects" (Knorr-Cetina, 1999, p.29).

The detailed ethnographic work by Knorr-Cetina (1999) on the epistemic cultures of high energy physics and molecular biology is generally taken as illustrative of social studies of science from a 'micro'-perspective. By underlining the variety of cultures of knowledge production, Knorr-Cetina (1999) challenged the perspective of a unified science, where there is only one type of knowledge and only one scientific method — which is commonly posited, albeit implicitly, by macro analyses. Using micro analyses of science in support of research policy-making is less common, however, due to the finer level of granularity and difficulties with comfortable generalisation of findings to national systems of research.

In line with the notion of epistemic cultures, investigations of the dynamics of knowledge production should place emphasis on knowledge as practised within structures, processes, and environments that make up specific epistemic settings. The literature is poor, however, in studies that apply Knorr-Cetina's (1999) notion of

epistemic cultures towards the contexts of developing countries. Exceptions are studies by Saloma-Akpedonu (2007), who examined how Malaysian and Filipino IT professionals who are developing Internet-based products perform epistemic work; and Menkhoff *et al.* (2010), who advocated the relevance of developing an appropriate and vibrant epistemic culture of innovative knowledge production in selected developing economies from Asia.

Developing a framework that mediates between the contrasting approaches of 'macro' and 'micro' analyses of science has been an object of continuous interest in sociological theory (Sibeon, 1999; Turner and Boyns, 2001). Here it is worth noting, however, that the terms 'macro', 'meso', and 'micro' are relative. In the continuum from the macro to the micro, what is macro from one's perspective may be micro from another's, as Eulau (1986, p.90) noted:

> *[…] what in this continuum is micro and what is macro depends on the point on the micro-macro scale where the observer 'dips in', where he fixes his object unit of analysis.*

Since these are relative terms, more important than distinguishing 'macro' (large and impersonal) from 'micro' (small and interpersonal), however, is the understanding of the crucial linkage between 'systemic' and 'social'. Archer (1995, p.11) explained:

> *Systemic properties are always the ('macro') context confronted by ('micro') social interaction, whilst social activities between people ('micro') represent the environment in which the ('macro') features of systems are either reproduced or transformed.*

Combining macro and micro perspectives — systemic and social considerations — might prove a fruitful way of understanding the complexities of contemporary research systems in the context of developing countries.

2.4. Theoretical foundations of 'information governance'

This section reviews the theoretical grounds upon which the notion of 'information governance', as a new, holistic approach to information in the context of research organisations is based.

2.4.1. The 'Information Society'

The development of the modern ICTs in the last years of the 20th century can be compared, in terms of its significance, to the invention of printing with mobile characters in the 15th century. The information explosion that accompanied these technologies' appearance drew attention to the consolidation of a new social configuration where information, knowledge and innovation correspond to richness and competitive advantage.

Although the word 'information' is not emphasised in all accounts that summarise the recent modifications of the society — such as 'Information Society', 'Risk Society', 'Globalisation', 'Postmodern Society', 'Knowledge Society', among others — basically all accounts recognise that information-related issues are vital to the claimed transformations. Information is currently produced by and distributed to a meaningfully higher number of people, and the competence of producing, registering, giving access and using information has become a determinant factor in the sustainability and competitiveness of economies, organisations, and individuals.

The origins of the concept 'Information Society' are controversial, however. A group of authors (Crawford, 1983; Cawkell, 1986; Duff *et al.*, 1996) claim for American provenance, stating that the notion was implicit in Fritz Machlup's conceptualisation of the *Knowledge Industry*, which was presented in the book '*The Production and Distribution of Knowledge in the United States'* from 1962 (Machlup, 1962). A second group (Morris-Suzuki, 1988; Ito, 1991) claims that the Information Society concept first appeared in Japanese government reports dating from 1969. The first English-language use of the term Information Society to be accepted by both American and Japanese accounts (Duff *et al.*, 1996), however, was made by Masuda (1970) in conference proceedings from 1970. In the following years, the concept spread widely across the Library and Information Science literature, with all its variants.

Masuda (1983, p.29) defined the Information Society as a new type of human society in which the production of information values would replace material values as "the driving force behind the formation and development of society". For Castells (1996, p.470), the Information Society has a network-based social structure: a "highly dynamic, open system, susceptible to innovating without threatening its balance". The notion of 'information capitalism' was then coined as in reference to the rapid

spread of information through networks which fundamentally alter the organisation of the capitalistic economy (Castells, 1996).

Understanding the relevance of information in current times leads to a fundamental question. What, precisely, is 'information'?

2.4.2. The ambiguity of the term 'information'

Distinguishing the concept of 'information' from those of 'knowledge' and 'data' has attracted considerable attention of scholars — not much consensus having been achieved so far. It is generally accepted, however, that data, information, and knowledge are interrelated concepts. Thus, it is difficult to explain knowledge without referring to information, as it is to describe information without mentioning data. For Feather and Sturges (2003, p.341), for example, knowledge is "information evaluated and organized in the human mind so that it can be used purposefully". From a similar perspective, Davenport *et al.* (1998, p.43) defined knowledge as "information combined with experience, context, interpretation and reflection".

Despite their conceptual interrelatedness, however, 'information management' and 'knowledge management' studies have specialised as different bodies of knowledge. Analogously, traditional management approaches in organisations also tend to treat 'information', 'knowledge', and 'data' separately. This might cause considerable confusion, though, given their high levels of complementarity and interdependence:

> *Knowledge management and information management not only dispose of similar [computer-based] tools and goals but are also based on similar methods and face similar problems. (Lueg, 2001, pp.151–152)*

The term 'knowledge management' — meaning the processes of capturing, distributing, and effectively using knowledge (Davenport and Prusak, 1998) — is surprisingly recent in the literature, dating from the mid-nineties. 'Information

management' [15] emerged earlier: some authors date it back to the Paperwork Reduction Act of 1980, which required federal agencies in the United States to introduce information resource management (Schlögl, 2005). It has been argued, however, that while data and information can be managed, knowledge (defined as 'what we know') cannot (Krogh *et al.*, 2000). Speaking of knowledge management, therefore, would be 'nonsense', to use Wilson's (2013) words.

Taking a pragmatic approach to the subject, Buckland (1991) identified three different uses of the word 'information'. First, it is attributed to physical representations of knowledge, i.e. objects, data or documents "that are referred to as "information" because they are regarded as being informative" (Buckland, 1991, p.351), a use that was named 'information-as-thing'. The second use of the word information refers to the act of informing: "the action of telling or fact of being told of something", which Buckland (1991, p.351) designated 'information-as-process'. In its third sense, information is used as equivalent to knowledge, or "that which is perceived in 'information-as-process" (Buckland, 1991, p.351), which the author named 'information-as-knowledge'.

Each of the three connotations — 'information-as-thing', '-as-process', and '-as-knowledge' (Buckland, 1991) — represents a legitimate perspective that deserves the attention of information-intensive organisations in current times. To be sustainable and succeed in the Information Society, organisations are to effectively cope with 'information' in all three connotations of the term.

The literature of Information Science lacks relevant studies that approach information from such an integrative perspective. This is possibly due to the intangible nature of ''information-as-knowledge', which as such, cannot be manipulated or 'managed'. However, actions can be taken to enable 'information-as-process' to take place and

[15] Information management is the "application of management principles to the acquisition, organization, control, dissemination and use of information relevant to the effective operation of organizations of all kinds" (Wilson, 2003, p.263).

'information-as-knowledge' to be created and shared in support of an organisation's business. This might all be part of an organisational 'information governance' approach, the development of which is the focus of this study.

2.4.3. Conceptions of 'information governance' from the literature

The roots of the English word 'governance' can be traced back to the Greek verb *κυβερνάω*, from the 14th century, which means 'to steer' (Rampersad and Hussain, 2014). By the end of the 17th century, though, the word governance would stand for a 'method of management', and recently it is mostly associated with the idea of 'corporate governance'.

Although a generally accepted definition has not been reached yet, corporate governance is nowadays largely understood as "the structures, process, cultures and systems that engender the successful operation of the organisations" (Keasey *et al.*, 1997, p.2). Another definition of corporate governance places emphasis on the use and control of organisational resources:

> *[Corporate governance is] the determination of the broad uses to which organizational resources will be deployed and the resolution of conflicts among the myriad participants in organizations. (Daily et al., 2003, p.371)*

Here, it is worthy clarifying the difference between the terms 'governance' and 'management', as applied to the corporate world. As explained by Too and Weaver (2013, p.4), the governance system "defines the structures used by the organization, allocates rights and responsibilities within those structures and requires assurance that management is operating effectively and properly within the defined structures". To put it another way, 'governance' relates to making decisions or delegating decision-making to the competent structures within the organisation, with focus on higher level matters of strategy and policy. The role of 'management', on the other hand, would be to operate the organisation within the framework defined by the governance system, ensuring that resources of all types are being effectively used (Too and Weaver, 2013).

Since the appropriate use and application of information is of vital importance for organisations, information itself is an important subject for governance. The term

'information governance' (IG), however, is very recent in the literature, still loosely defined. Most works referring to the concept have approached records and data management, information confidentiality, security, and ownership issues (Donaldson and Walker, 2004; Gillies and Howard, 2005; Huston, 2005; Manwani *et al.*, 2007; Caldwell, 2008; Williams, 2008; Lomas, 2010).

The earliest mention of the concept was made by Donaldson and Walker (2004), which developed an IG framework to support UK's National Health Service (NHS) on security and confidentiality of electronically-stored information. The NHS approach for the governance of its information resources is known as the 'HORUS' model. The acronym means that information collected and processed about patients must be: Held securely and confidentially; Obtained fairly and lawfully; Recorded accurately and reliably; Used effectively and ethically; and Shared appropriately and legally (Donaldson and Walker, 2004).

From a different point of view — that of politics and public administration — IG is discussed in the literature as the acknowledgment of the right of access to public information. As such, it applies to public administration organisms that show opening (offer comprehensive information and maintain regular communication with other organisations), transparency (offer concrete and understandable information to citizens), and accessibility (citizens/users can easily interact with the sources of information) (Gonzalez de Gómez, 2002).

The term IG is also commonly used in the literature as equal to 'Information Technology (IT) governance'. In the IT world, the term is well established, and means:

> *the organizational capacity exercised by the board, executive management, and IT management to control the formulation and implementation of IT strategy and in this way ensure the fusion of business and IT. (Grembergen, 2004, p.5)*

Kooper *et al.* (2011) argued that the concept of IT governance leaves unanswered several information-related questions. In his opinion, governance of IT and IG are very different matters. The interchangeable misuse of the two terms reflects a technocratic approach taken by many organisations, which focus primarily on the adoption of technology as a way to sort information-related issues. The focus of organisations on

IT governance, instead of information, has been reported by Davenport and Prusak (1997, p.68 - emphasis added):

> *many observers acknowledge the importance of information technology governance but still ignore information politics [...] Yet I believe focusing on the **governance of information** is equally important, if not more so. Which matters more — who operates the data center, or who decides what information will be gathered and used within a firm? Are personal standards more important than information standards?*

In the quote above, Davenport and Prusak (1997) speak of information politics and governance of information as synonyms. According to Davenport *et al.* (1992), every organisation has an established model of information politics — their explicit choice or not — which they illustrated through a political metaphor. Besides the technocratic approach, Davenport *et al.* (1992) identified four other political models (**Table 3**) that are commonly assumed by organisations, coming to conclude that the wrong political structure can sink any efforts to create information-based organisations.

Table 3. Models of information politics. (source: Davenport *et al.*, 1992, p.56)

Model	Description
Technocratic Utopianism	A heavily technical approach to information management stressing categorisation and modelling of an organisation's full information assets, with heavy reliance on emerging technologies.
Anarchy	The absence of any overall information management policy, leaving individuals to obtain and manage their own information.
Feudalism	The management of information by individual business units or functions, which define their own information needs and report only limited information to the overall corporation.
Monarchy	The definition of information categories and reporting structures by the firm's leaders, who may or may not share the information willingly after collecting it.
Federalism	An approach to information management based on consensus and negotiation on the organisation's key information elements and reporting structures.

In their empirical studies, Davenport *et al.* (1992) assessed the different political models along four dimensions: (i) commonality of vocabulary and meaning; (ii) degree of access to important information; (iii) quality of information (currency, relevance, and accuracy); and (iv) efficiency of information management. Each of these dimensions reaches its highest levels in federative political models.

The political models form a continuum of local vs. centralised control of the information environment: 'Monarchy' and 'Federalism' being "the only two viable choices among the five models" (Davenport *et al.*, 1992, p.60). Given that the information politics (or IG) model is not always an explicit choice, organisations should assess the model that is in place and work towards moving from the less effective (like

'Anarchy' and 'Technocratic Utopianism') to the more effective ones (**Figure 5**). Typically, however, more than one model is present in an organisation, which confuses information managers and consumes scarce resources (Davenport *et al.*, 1992).

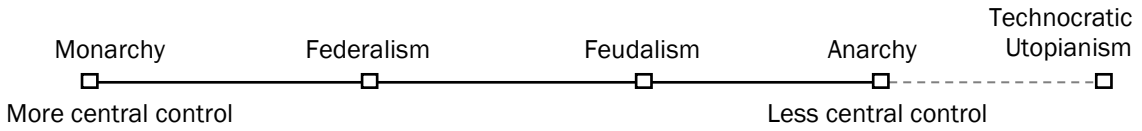


Figure 5. Continuum of information politics models. (adapted from: Davenport and Prusak, 1997, p.69)

In the continuum proposed by Davenport and Prusak (1997), Technocratic Utopianism stands apart from the other governance models. The reason for that is because this model presuposes a misunderstanding, by managers, of the nature of information issues. Technocratic Utopianism, therefore, is not properly an IG model, since IT — and not information — is at the centre of the governance process. That is why Technocratic Utopianism is almost never a concious choice of managers, unlike the other models. Nonetheless, it is one of the most common IG models, either on its own or alongside another model (Davenport and Prusak, 1997).

Kooper *et al.* (2011) proposed a definition of IG that sheds light onto the use and application of information. As an approach to better govern the use of information within and outside the organisation, their notion of IG involves:

> *[...] establishing an environment and opportunities, rules and decision-making rights for the valuation, creation, collection, analysis, distribution, storage, use and control of information. (Kooper et al., 2011, pp.195–196)*

A previous article by an author from the same group stated that IG is concerned with the "appropriate use of information based on a deep understanding of the information culture" (Maes, 2007, p.12). The term 'information use', in Maes' (2007) definition, encompasses the selection and processing of information in order to answer a question, to solve a problem, to make a decision, to negotiate a position or to understand a situation (Choo, 1998). The term 'information culture', however — which has been correlated with IG in a few other studies (Oliver, 2004, 2008; Kooper *et al.*, 2011) — has two different uses in the literature.

Some authors (Chepaitis, 1994; Curry and Moore, 2003) perceive 'information culture' as a type of organisational culture where the value of information is recognised and

where decisions are made based on information. Simply put, an information culture is a culture where "information is the essence of all activities" (Khan and Azmi, 2005, p.37). From this perspective, not all organisations have information cultures; instead, they might pursue one.

A second group of authors (Oliver, 2004; Choo *et al.*, 2008), of which Maes (2007) is part, perceive information culture as the interactions of the organisational culture with information and its management, shaped by attitudes towards and values of information. For Choo *et al.* (2008, p.792), information culture is "the socially shared patterns of behaviors, norms, and values that define the significance and use of information". From this standpoint, every organisation has an information culture — whether or not it facilitates the management of information, and whether or not it is beneficial for the organisation's business — this being the connotation adopted in this thesis.

Most of the elements and building blocks of the IG framework of Maes (2007) and Kooper *et al.* (2011), however, are not new but share the same principles of a well-built information management approach. Davenport's (1997) 'ecological' approach to information management, for instance, emphasises an organisation's entire information environment, addressing cultural and political issues, behaviour and work processes, and technological aspects.

The main difference between this study's approach to IG and traditional information management and knowledge management frameworks — including Davenport's (1997) 'information ecology' model — is that it aims to offer a single, managerially-useful construct for organisations to cope with 'information-as-thing', '-as-process', and '-as-knowledge' (Buckland, 1991) in articulated fashion. All the potential of the IG framework proposed in this thesis, therefore, lies in harnessing and ensuring highly connected interaction between traditionally separated managerial approaches towards each dimension of information. Other differences are highlighted in the following section, which presents the theoretical framework of this study.

2.5. Theoretical framework of this study

Having reviewed the literature, a theoretical framework was constructed to guide the investigation of IG as a holistic, integrative approach to information in research organisations. The theoretical framework reflects the systems way of thinking that is at the core of this study. The main underlying assumption was that efforts to improve the IG in research organisations would not succeed if socio-cultural aspects were ignored. To circumvent that, the IG framework should be built upon an understanding of what it really meant to do agricultural research in Brazil, from a systems perspective.

The problem situation (Checkland, 1981) of concern is therefore investigated by means of a two-level analysis — each systemic level having its associated theoretical underpinnings[16]. The dynamics of the wider Brazilian agricultural research system comprises the 'macro-level' of analysis, while the local practices and culture of agricultural knowledge production at the Brazilian Agricultural Research Corporation (Embrapa) entail the 'meso-level' of analysis. Each systemic level is embedded in the other and both are considered in the context of IG at Embrapa. This will allow appreciation of both systemic and social aspects of relevance and, consequently, more deep understanding of the complexities of IG in a research organisation.

Two fundamental assumptions underpin the macro-level analysis. The first is the notion of 'science as a complex and dynamic social institution' (Kuhn, 1962). It follows that there is no unified way of doing research, no universal norms and values, but multiple research systems with features that may change in time and space. Research systems that operate in the context of developing countries, for instance, might work differently from those of the highly developed nations (in which the conceptualisations of changing research systems reviewed in section 2.3 were produced). Nonetheless, those macro-theories — particularly, 'Mode 2 Knowledge Production' (Gibbons *et al.*, 1994), for appreciating the role of a broader range of institutions in the advancement

[16] The 'rich picture' (Checkland, 1981) presented in **Figure 1** (*Chapter One*) illustrates.

of science — provide a second theoretical foundation in the analysis of the Brazilian agricultural research system from a macro perspective.

Using the term 'macro' is not to mean, however, that an empirical foundation is lacking at this level of analysis. A participant-centred approach guarantees that broad statements about the functioning of the wider research system (macro-properties)[17] are empirically well-founded. In this study, properties of the macro-level of analysis are, therefore, macro-constructions deriving from participants' representations of the whole agricultural research system in Brazil.

The agricultural research system in Brazil may be interpreted, therefore, as a social system — "a process of fulfilment of a purpose, or the pursuit of a goal" (Skyttner, 2005, p.390). The purpose of this system is to transform a relevant set of inputs into knowledge, the ultimate outcome of the research process. As a social system, it is kept together by cultural values, social relations (e.g. notions, norms) and social actions (e.g. co-operation, conflict, communication) (Johannessen and Olaisen, 2005). These cultural and social aspects, however, are not observable at the macro-context of the wider agricultural research system, neither at the micro-level of individual researchers, but in-between: at the 'meso-level'[18] where the transformative processes of inputs into outputs take place. Very little is understood, however, about the transformative processes through which agricultural knowledge is produced out of a set of inputs (such as financial, physical, or information resources). What is known, for certain, is that the knowledge produced in result feeds constantly back into the system

[17] A useful analogy for the macro-level approach is that of a bird's-eye perspective, which is close enough to observe ground-level events.

[18] As stated in section 2.3.9, what is 'macro', what is 'meso', and what is 'micro' in a social system is a choice of the researcher (Eulau, 1986). In the social system investigated in this thesis, a micro-level of analysis would focus on the individual actions of researchers. Examining the micro-level was not a purpose of this study, however, since "once a social system is in place, individuals become replaceable to some extent; their roles can be enacted by different persons" (Bunge, 2000, pp.149-150), due to cultural forces. Here, the meso-level fits between the micro-level of individual's actions and the macro-level of their representations of the wider agricultural research system in Brazil. From this study's perspective, therefore, epistemic cultures are noticeable at a meso-level of analysis.

as a crucial input. Knowledge, however, is intangible and difficult to assess, which makes this system a very complex one.

Latour (1999) spoke of the unknown nature of the scientific process through the abstract notion of a 'black box'. By 'black boxing' in science, Latour (1999) meant the way scientific and technical work is made invisible by its own success: the more successful is science, the more opaque and obscure it becomes. Although observable elements enter the black box and outputs are generated by the system, little is known about the processes happening inside the imaginary black box that is the research activity. Understanding the social, transformative processes through which agricultural knowledge is produced out of a set of inputs equals understanding the 'machineries of knowledge production', which Knorr-Cetina (1999) named 'epistemic cultures' — this, being the main theoretical assumption behind the meso-level analysis (**Figure 6**).



Figure 6. A black box represents the unknown in the research activity.

While individuals are concrete entities, social systems are constructs which explain individual preferences, decisions and actions. It is assumed, therefore, that features of the wider research system might influence the work of researchers and have potential implications for the governance of information in a research organisation. Correlating between the macro-level, the meso-level and the governance of information, thus, is an important step towards developing a framework for effective governance of information in research organisations.

There are a few other premises upon which the IG framework, as a main outcome of this study, shall rest. First, the IG framework should allow for an 'integrative' view on the three connotations of information: 'information-as-thing', '-as-process', and '-as-knowledge' (Buckland, 1991). And as already said, the framework shall be developed upon a deep understanding of the research context from a macro and a meso perspective. That is, it shall be 'systemically' and 'culturally-grounded'.

This study acknowledges interrelations between the information culture of an organisation and IG. Therefore, 'culturally-grounded' means not only that the IG framework shall take into account the epistemic culture of agricultural researchers

but, also importantly, it shall be built upon an understanding of the organisational 'information culture'. In line with the conceptually integrative view of information pursued in this thesis, the term information culture is used here to mean 'the whole of the interactions of individuals with information — '-as-thing', '-as-process', and '-as-knowledge' — within the organisation'. The perspective is that every organisation has an information culture, which can or cannot facilitate the governance of information. Accordingly, every organisation possesses an IG model, however effective or not it is.

Instead of focusing on the information behaviours of individual researchers (which would match a micro-level analysis), approaching the information culture sheds light onto the social aspects that influence their attitudes towards information (which is perceived at a meso-level of analysis). People might change, join and leave the organisation, but cultural forces remain in play, influencing and determining shared patterns of behaviour.

The diagram below presents the main assumptions that inform the theoretical framework of this study and the critical factors that should be incorporated into the development of a framework for effective governance of information in a public research organisation (**Figure 7**).

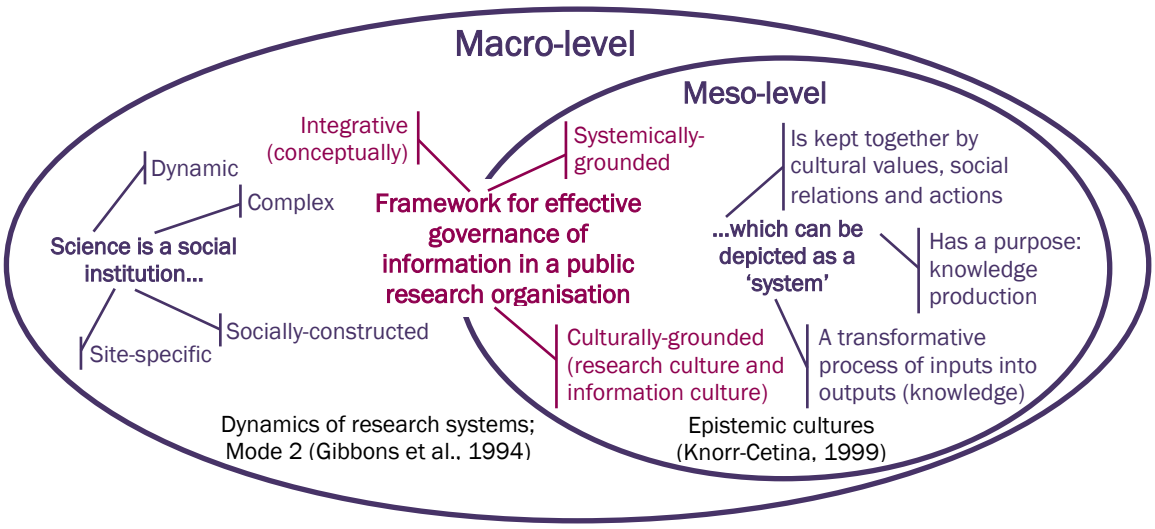


Figure 7. Theoretical framework of this study, as related to each systemic level of analysis.

The next chapter presents an overview of research traditions and philosophies, describes Soft Systems Methodology (Checkland, 1981) as the main analytical framework of this study and details the whole methodological approach undertaken in

the development of the integrative, systemically and culturally-grounded framework for effective governance of information in research organisations.

2.6. Summary

This chapter commenced by presenting a critical review of the theoretical underpinnings of this study. The analysis of available macro and micro studies of science revealed a gap in the literature in relation to the dynamics of science in the context of developing countries and from the perspective of public research organisations. This analysis also highlighted the relevance of developing a framework that mediates between the usually contrasting approaches of 'macro' and 'micro' analyses of science.

The chapter then shifted to discuss the theoretical grounds upon which the notion of 'information governance', as a new, holistic approach to information in the context of research organisations is to be constructed. Other gaps in the literature were demonstrated, in terms of studies that approach information issues in the context of the research activity and from a conceptually integrative standpoint, despite the interrelatedness and comparable relevance of 'information-as-thing', '-as-process', and '-as-knowledge' (Buckland, 1991) for contemporary organisations.

Next, the guiding set of assumptions that inform the theoretical framework of this study was presented. Reflecting the systemic approach that is at the core of this study, these assumptions were presented as related to each level of analysis. The fundamental assumptions underpinning the macro-level analysis (the analysis of the Brazilian agricultural research system from a macro perspective) are: the notion of science as a complex and dynamic social institution; and Mode 2 theory (Gibbons *et al.*, 1994). Behind the meso-level analysis is the notion that: as with any social system, the Brazilian agricultural research system can be described in terms of inputs being transformed into outputs. Understanding the transformative processes through which agricultural knowledge is produced out of a set of inputs equals understanding the 'epistemic culture' of agricultural research (Knorr-Cetina, 1999).

Another set of premises was presented, upon which the IG framework, as a main outcome of this study, shall rest. First, the IG framework should allow for an

‘integrative’ view on the three perspectives of information: ‘information-as-thing’, ‘-as-process’, and ‘-as-knowledge’ (Buckland, 1991). Second, the framework shall be developed upon a deep understanding of the research context, at both a macro and a meso perspective, and the organisational information culture. That is, it shall be ‘systemically’ and ‘culturally-grounded’. Correlating between the macro-level, the meso-level and the governance of information was then stated as a crucial step towards more effective governance of information in research organisations.

Chapter Three. RESEARCH METHODOLOGY

There is this hope, I cannot promise you whether or when it will be realized — that the mechanistic paradigm, with all its implications in science as well as in society and our own private life, will be replaced by an organismic or systems paradigm that will offer new pathways for our presently schizophrenic and self-destructive civilization.

(Bertalanffy, 1968, p.45)

3.1 Introduction

Scientific investigations address research problems through a variety of methodological approaches[19]. In order to determine the research method that best fits a particular investigation, researchers need to consider the nature of the research question, the context to be investigated, the accumulated knowledge in the problem area, and decide on a philosophical approach.

The preceding chapters have explained the problem situation of concern and the questions that motivated this study. Brief introductions to the context investigated; the choice of methods and the philosophical stance were given (*Chapter One*). Then, after discussing the main theoretical perspectives associated with the issue of information governance (IG) in research organisations, the theoretical framework of this study was presented (*Chapter Two*). In the current chapter, the philosophical underpinnings of this study are developed further; details of the whole methodological approach are presented and background information to the case study is provided.

The chapter commences with an overview of research traditions and philosophies (section 3.2), with emphasis on qualitative research, interpretivism/phenomenology,

[19] The terms 'methodology' and 'methods' are often used interchangeably in the literature. In this research, the term methodology is used in agreement with Strauss and Corbin (1998, p.4) to mean "a way of thinking about and studying social reality". The methodology, therefore, is the link between theory and methods in a given investigation; it explains and justifies the choice of methods, instruments, tools and procedures used for gathering and analysing research data.

and soft systems thinking. Relevant background information to the case study is then offered in section 3.3. After that, the procedures undertaken for data gathering (section 3.4) and data management and analysis are detailed (section 3.5). Finally, section 3.6 is a summary of this chapter.

3.2 Research traditions and philosophies

Research traditions and philosophies can be distinguished in many different ways. In order to situate the methodological and philosophical principles of this study in the wider context, the traditional divides between 'qualitative' and 'quantitative' research, 'positivism' and 'interpretivism', 'soft' and 'hard' thinking are briefly reviewed in sections 3.2.1 to 3.2.3. Soft Systems Methodology (SSM), as a process of inquiry, its uses and limitations are discussed in section 3.2.4.

3.2.1 'Qualitative' *vs.* 'quantitative' research traditions

The differences between 'qualitative' and 'quantitative' approaches to research have received considerable attention in the literature (Smith, 1983; Wilson, 1986; Husén, 1997; Tashakkori and Teddlie, 1998; Bernard, 2000; Johnson and Onwuegbuzie, 2004; O'Leary, 2004). In short, quantitative methodologies involve the collection and analysis of numerical data, focusing on measurable variations between and among variables (Husén, 1997), while qualitative methodologies use "forms of data collection and analysis which rely on understanding, with an emphasis on meanings" (Scott and Marshall, 2005, p.538). Most commonly, the raw material for qualitative studies is ordinary language — i.e. data which is presented in the form of words — thus allowing appreciation of complex social meanings.

During most of the last century, advocates of quantitative and qualitative research have disagreed passionately on how social issues should be scientifically treated (Johnson and Onwuegbuzie, 2004). While quantitative research supporters contended that social science inquiry should be objective (Ayer, 1959; Popper, 1959; Schrag, 1992; Maxwell and Delaney, 2004), defenders of qualitative research argued for the superiority of more subjective, interpretivist approaches (Lincoln and Guba, 1985; Guba and Lincoln, 1989; Schwandt, 2000). It was not until a few decades ago that quantitative and qualitative methods began to be combined to form what could be

called the third research tradition — 'mixed-methods research' or 'mixed research' (Brewer and Hunter, 1989; Greene *et al.*, 1989; Tashakkori and Teddlie, 1998), which is "a method and philosophy that attempt to fit together the insights provided by qualitative and quantitative research into a workable solution" (Johnson and Onwuegbuzie, 2004, p.16).

3.2.2 'Positivist' vs. 'interpretivist' epistemological positions

The distinction between qualitative and quantitative research is often linked to particular epistemological positions. Quantitative methodology is largely associated with the 'positivist' epistemology, while qualitative research is usually coupled with the 'interpretative' epistemology.

The epistemological stance of positivism values an objective, empiricist approach to science in which knowledge is based on systematic observation and experimentation (Walliman, 2006). This somewhat rigid perspective is mainly exemplified by natural science research — although a positivist orientation can also occur in the social sciences, when reality is assumed to be observable, stable, and measurable.

'Interpretivism', on the other hand, challenges the appropriateness of traditional science methods for investigating the meaningful nature of social and cultural phenomena. An interpretative perspective on science assumes that no single, observable reality exists; instead, reality is relative and socially constructed. Since multiple interpretations may occur for the same event, research from this epistemological position is usually aimed at understanding and interpreting motives, meanings, reasons, and other subjective perceptions which are time and context bound (Carson *et al.*, 2001). From an interpretivist standpoint, therefore, social reality is not some "thing" that can be interpreted in different ways; "it is **those** interpretations" (Blaikie, 1991, p.120 - emphasis added).

Interpretivism is closely related to the philosophical tradition of 'phenomenology', which is based on the notion that the social world is constructed by individuals in their actions, interactions, and the meanings they attach to these activities. The reality is thus a complex set of socially constructed meanings — "people's experiences and ways of viewing the world" (Backer *et al.*, 2002, p.76) — which are systematically assessed in phenomenological studies.

Typically, phenomenological approaches involve in-depth interviewing of individuals who have experienced a phenomenon of interest, the 'essence' of which is something individuals usually share with others living the same experience. Identifying the 'essence' is, therefore, the main focus of phenomenological studies. By using qualitative interpretative analysis, it is possible to:

> *describe, decode, translate, and otherwise come to terms with the meaning, not the frequency, of certain more or less naturally occurring phenomena in the social world. (Maanen, 1979, p.520)*

Examples of interpretative qualitative research methods include: discourse analysis (Potter and Wetherell, 1987), ethnography (Becker, 1970), empirical phenomenology (Wertz, 1983; Giorgi, 1985), hermeneutic-interpretative research (Packer and Addison, 1989), interpretative phenomenological analysis (Smith *et al.*, 1999), consensual qualitative research (Hill *et al.*, 1997), grounded theory (Strauss and Corbin, 1998), and Soft Systems Methodology (Checkland, 1981).

3.2.3 'Hard' vs. 'soft' divide and the rise of 'soft systems thinking'

The terms 'hard' and 'soft' are commonly used to distinguish branches of scientific traditions. Objectivist, scientific disciplines with strong roots in the epistemological stance of positivism are collectively referred to as 'hard' sciences. Alternatively, subjectivist, social sciences, rooted in interpretivism are usually called 'soft' sciences (Crawford and Pollack, 2004).

The hard tradition of science understands the world as an objective reality formed by hard 'systems': "mechanistic processes, with stable, or predictably varying, relationships between the relevant variables" (Crawford and Pollack, 2004, p.646). In order to understand complex phenomena, a hard systems perspective focuses on the properties of the parts, so that the behaviour of the whole could be deduced, which is associated with the tradition of 'reductionism'. An organism, for instance, would be described at different levels and through varied approaches — say, in anatomical, biochemical or functional terms — as an effort to create a comprehensive picture. The absence of unifying principles, however, would make these disconnected approaches inappropriate for solving complex and interlinked natural phenomena.

Systems thinking emerged in this context, looking for properties applicable to a collection of parts of a system, as a way to understand how things are "compounded and work together in integrated wholes" (Skyttner, 2005, p.V). Understanding would then progress, from the whole to its parts, in a mechanism named 'synthesis'. The three steps of synthesis are: identifying the system of which the unit in focus is part; explaining the properties or behaviour of the system; and finally, explaining the properties or behaviour of the unit in focus, as part or function of the system. Therefore, synthesis does not create detailed knowledge of the structure of a system: it explains, more than describes phenomena of interest (Skyttner, 2005).

Since the first studies in the 1940's, systems thinking solidified as an alternative for investigating biological phenomena by regarding organisms as whole entities, or systems, in opposition to reductionism and mechanistic thinking (Flood and Jackson, 1991). For embracing the complexity of phenomena from the beginning, systems thinking responded to reductionist analyses with 'expansionism'. That is, it expanded the focus of the observer, instead of reducing it, as Skyttner (2005, p.34) asserted: "analysis gives description and knowledge; systems thinking gives explanation and understanding".

One of the main aspirations of the systems thinking movement was to create a 'general systems theory' which would set out the laws governing the behaviour of all systems, whatever their type. General systems theory assumed that systems exist in the real world and "that our models of them represent (as near as possible) comprehensive knowledge" (Midgley, 2001, p.36). Noticeably, the systems movement failed to produce such a general theory, but it did not take long until the notion found application in the study of a broader range of systems, besides biological ones. The fundaments of systems thinking, however, needed to be adjusted to handle 'soft issues' [20], which are subjective and complex by nature, allowing several equally

[20] 'Soft issues' have a cultural/social facet. Examples are issues related to community perception, political and social impacts, conflicts of interest among stakeholders, and communication-related issues, to name just a few.

possible perspectives. Moreover, soft problems do not usually fit into traditional disciplinary limits, but require a multi- or inter-disciplinary approach.

Instead of describing the world through systems which can be engineered ('hard' systems thinking), soft systems thinking emerged as a way to inquire into real world complexity by using systems for learning (Checkland, 1981). While intervening in and improving complex problem situations, reductionism is to be avoided and a commitment with a holistic and multidisciplinary perspective is necessary.

3.2.4 Soft Systems Methodology: uses and limitations

Peter Checkland's Soft System Methodology (SSM) is arguably the most prominent methodology of soft systems thinking, widely used in the UK and other regions of world (Mingers and Taylor, 1992; Wilson, 2001). The books 'Systems Thinking, Systems Practice' (Checkland, 1981), 'Soft Systems Methodology in Action' (Checkland and Scholes, 1990) and 'Information, Systems and Information Systems' (Checkland and Holwell, 1998b) are recognised as classics in the field.

SSM was developed as a tool to investigate complex organisational issues through the perspective and understanding of human participants. More than thirty years of research 'on' SSM and 'use of' SSM have shaped what is now considered a well-tested and mature process of inquiry into real world problem situations[21]. Philosophically, the methodology has its roots on the interpretivist and phenomenological traditions, thus concentrating on the nature and content of our thinking about the world, "rather than the world itself as something independent of all observers of it, which is the world of positivism" (Checkland, 1981, p.273).

[21] The problem situation can be ill-structured, semi-structured or highly-structured, depending on how easily it can be described in a concise, complete manner. While addressing a problem situation, however, effort must be made to avoid structuring the situation in anticipation and closing down original thinking and learning. The first step into addressing the problem situation should be, therefore, 'finding out' about it, as these situations are commonly characterised "by complex operations and management processes that may have grown over time, unclear and/or multiple objectives, changing environments and people with different attitudes, histories and agendas" (Wilson, 2001, p.1).

Soft systems models are abstract structures for understanding and interpreting problem situations, deriving from mental constructs of the participants — and not ways of stating how the real world 'is'. In SSM, each system has a purpose and systems concepts are used to provide guidance on choosing actions of improvement, in a way that is acceptable to key stakeholders involved (Checkland, 1981).

SSM is appropriate in pluralist contexts, where values and beliefs of participants diverge, but still there is a basic compatibility of interests which makes genuine compromise possible (Flood and Jackson, 1991). Particularly, the methodology is suitable for assessing 'ill-structured' or 'messy' problem contexts, where there is no clear view of "what constitutes the problem, or what action should be taken to overcome the difficulties being experiences" (Flood and Jackson, 1991, p.168).

As a process of inquiry, the traditional model of SSM comprises seven stages (**Figure 8**). In Stage 1, the unstructured problem situation being addressed is outlined. After gathering information through observation and interviewing, the problem situation is expressed (Stage 2). The main findings in Stages 1 and 2 can be summarised in a 'rich picture', i.e. a visual representation that highlights the issues, conflicts and any other interesting features of the problem situation. Through interfacing systems thinking with real world thinking from the rich picture, a number of themes surface, which can be captured as a set of relevant viewpoints, or 'relevant systems' — the purposeful activity that may promote action for improvement in the problem situation. In Stage 3, idealised views of what a relevant system should be are expressed through 'root definitions', involving six elements (Checkland, 1981) that form the mnemonic CATWOE: the Customers (victims and beneficiaries of the purposeful activity); the Actors (the ones who do the activities); the Transformation process (the purposeful activity which transforms an input into an output); the *Weltanschauung* [22] (the view of the world that makes the definition meaningful); the Owners (the ones who can stop the activity); and Environmental constraints.

[22] *Weltanschauung* is a German word that means 'worldview'.

In Stage 4, conceptual models are built, based on the root definitions. A conceptual model is an account of the activities which the ideal system must do in order to fulfil the requirements of the root definition. In Stage 5, conceptual models are compared with the reality in order to generate debate about the possible changes that could be made. In Stage 6, systemically-desirable and culturally-feasible changes are defined. And finally, Stage 7 means taking action, i.e. implementing the changes classified as both desirable and feasible (Flood and Jackson, 1991).

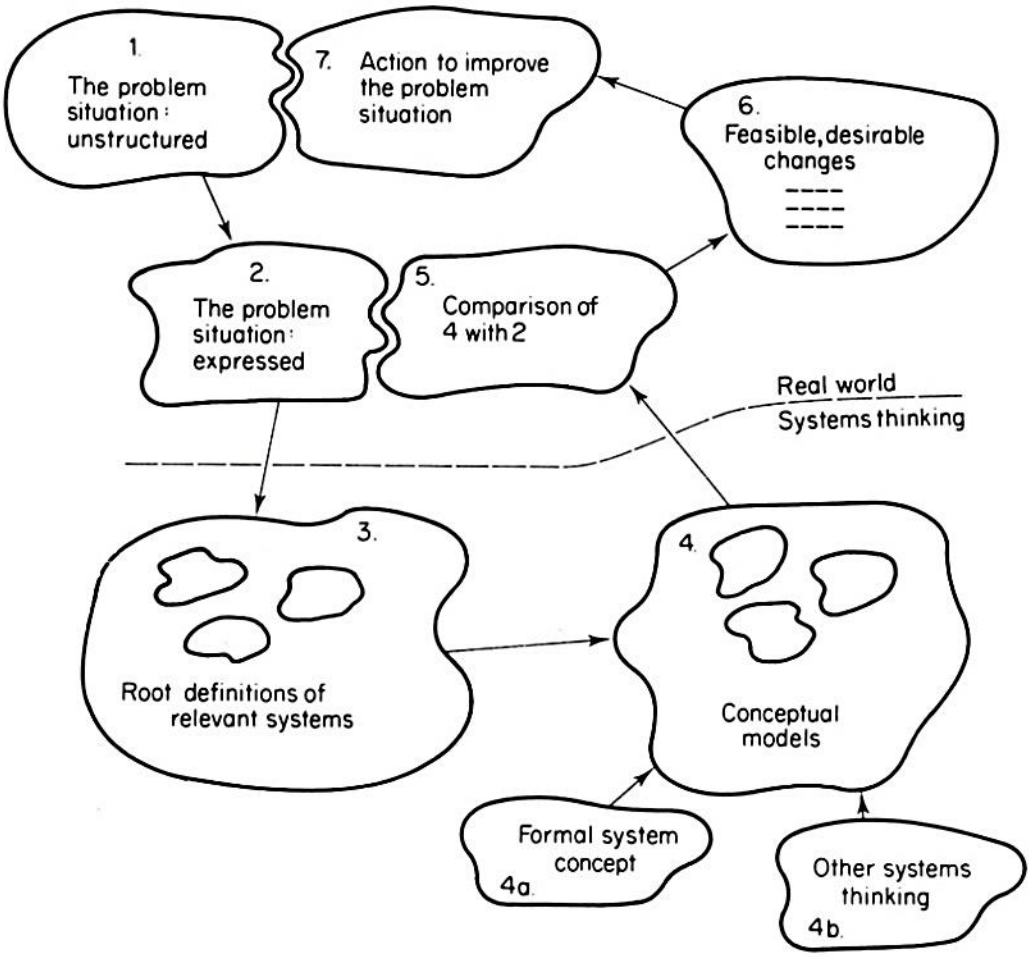


Figure 8. Seven-stage model of Soft Systems Methodology. (source: Checkland, 1981, p.163)

Acknowledging the significance of cultural and political aspects to any problem situation, SSM evolved in time to embody not only a logic-based stream of analysis (through the prescribed seven stages) but also a cultural and political stream, which enables reflection and judgement "about the accommodations between conflicting interests which might be reachable by the people concerned and which would enable action to be taken" (Checkland and Scholes, 1990, p.A14). The second book by Checkland and Scholes (1990) stimulated a more flexible use of SSM, through a new,

modified and revised, four-activity model (**Figure 9**), which became known as Mode 2 SSM.

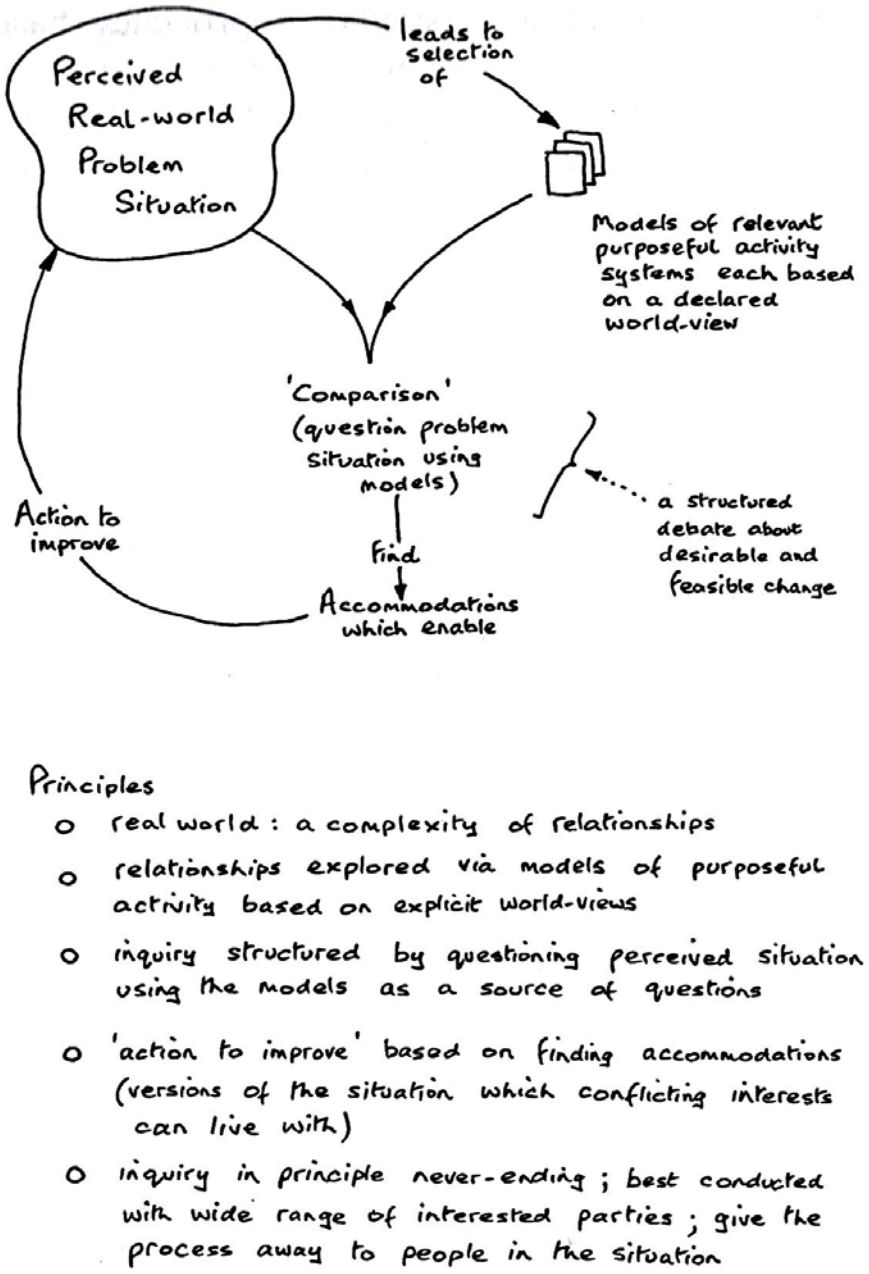


Figure 9. Learning/enquiring cycle of Mode 2 SSM. (source: Checkland, 1999, p.A9).

Rather than descriptive, the new model is symbolic, with an implied cultural stream of analysis. The four stages can be sharply defined as: (i) finding out about a problem situation, including culturally/politically; (ii) formulating some relevant purposeful activity-models; (iii) debating the situation, considering the changes that are both desirable and culturally-feasible, and the accommodations between conflicting interests which will enable action-to-improve to be taken; and (iv) taking action in the situation to bring about improvement (Checkland, 1999). Mode 2 SSM differs from the

seven-stage model by focusing more on interaction, instead of intervention; being more iterative and less sequential (Checkland and Scholes, 1990). Ideally, the modified version is to be used as an internalised model (not as an external recipe); a point of reference to make sense and cope with the complexity of real world problem situations. Flexible, non-linear moves among the stages must be guaranteed.

More recently, Checkland re-examined the dividing line between the 'real world' and the 'systems thinking' world (Tsouvalis and Checkland, 1996): 'above the line' was the real world of the problem situation and 'below the line', the consciously-organised systems thinking world (as shown in **Figure 8**). Tsouvalis and Checkland (1996, p.5) asserted that the divide, initially helpful in "drawing attention to the conscious use of systems thinking to explore real world complexity", implied a "false dualism" that contemporary, sophisticated uses of SSM should move beyond.

Most commonly, SSM has been used in case studies[23] as a specialised form of 'action research'[24]; a tool to learn about problem situations and improve practices in organisations, through participants' self-reflective enquiry. Rose (1997) identified five main uses of the methodology in scientific investigations: (i) as a problem-structuring tool towards soft or 'messy' problems; (ii) as a good-fit research tool, i.e. a qualitative, activity-based, interpretative, participative, systems-based, methodologically explicit tool; (iii) as a triangulation tool, to confirm, refute or amplify findings obtained by other method; (iv) as a theory-testing or generating tool; and finally, (v) as a coordinative or directive tool, with the research process itself being conceptualised as a purposeful human activity system, or to provide a common basis for transdisciplinary research.

The limitations of SSM are mainly related to the misuse of the methodology as a problem-solving tool, by practitioners. Practical limitations usually include an apparent

[23] A case study is a tool for data gathering through which one may look in depth at one (single-case), or a small number of organisations, social/political phenomenon or individuals (multiple-case); an empirical inquiry "that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (Yin, 1994, p.13).
[24] Checkland and Holwell (1998, p.9) defined 'action research' as the process in which "the researcher enters a real-world situation and aims both to improve it and to acquire knowledge".

lack of recognition of the importance of power and politics when recommending changes' implementation in organisations (Mingers, 1984, 2000). These limitations, however, are attenuated in scientific uses of the methodology.

3.3 Background information to the case study

This research employs an exploratory case study design to look in-depth at the problem situation of *information governance in the context of a research organisation*[25]. For the case study, Brazil serves as a model of a developing country, while agricultural science is taken as one of the country's most eminent contributions to the advancement of knowledge. Finally, the choice of the Brazilian Agricultural Research Corporation (Embrapa) as the context to be investigated in the case study is justified on the basis of its successful contribution to the advancement of agricultural knowledge; and for being a typical information-intensive environment.

The following subsections provide valuable background information to the case study, with focus on Embrapa's contribution to the development of Brazilian agriculture and the advancement of agricultural knowledge[26].

3.3.1 Overview of Brazil

Brazil — the name of which derives from a wood that abounded in the country in the past — was a colony of Portugal, since navigators' arrival on 22nd April 1500. The country gained independence from Portugal in 1822 and, almost seventy years later, Brazil was proclaimed a Federal Republic (15th November 1889). The national language is Portuguese and the currency is the Brazilian Real (R$).

Brazil is the largest country in South America (8,547,400 square kilometres) and the fifth largest in the world, with a population of 190,732,694 persons inhabiting the

[25] A pictorial representation ('rich picture') of the problem situation addressed in this thesis was offered in **Figure 1**, in the introductory chapter of this thesis.
[26] Part of section 3.3.2 is based on a previous publication (Bertin *et al.*, 2009).

26 states and Federal District in which the capital, Brasília, is located (Brazilian Institute of Geography and Statistics, 2010). Besides the world's largest tropical forest (the Amazon), a large supply of fresh water, abundant solar energy, and rich biodiversity, Brazil has over 200 million hectares of Savannahs (known as 'Cerrados'), with great agriculture and livestock production potential. A map of Brazil is presented in **Figure 10**, showing its organisation in States and main biomes[27].

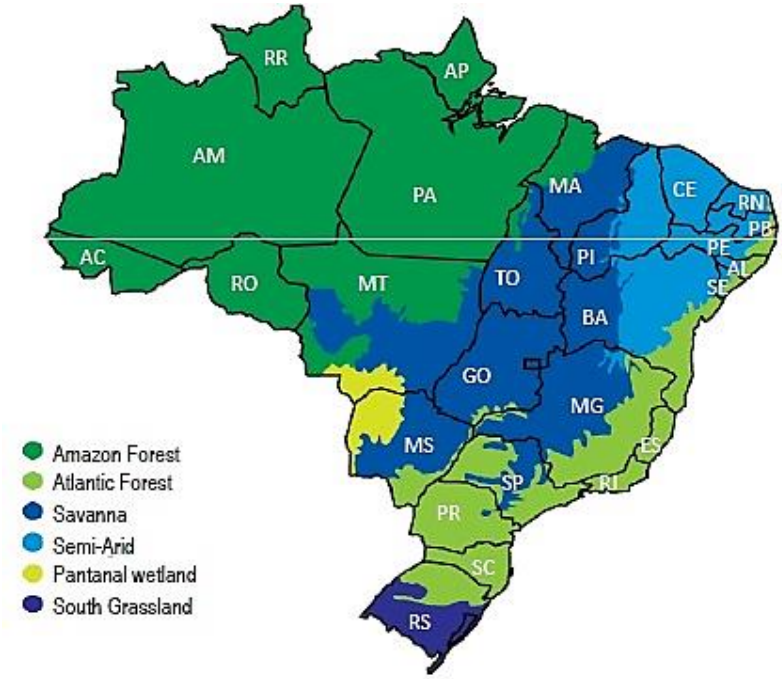


Figure 10. Map of Brazilian 26 States, Federal District, and six main biomes. (adapted from: Brazilian Institute of Geography and Statistics, 2004)

In a classification of all World Bank member countries and economies with populations of more than 30,000 persons (213 countries, in total), Brazil stands as an upper-middle income[28] developing country, together with 45 other countries (World Bank, 2010). Recently, the Brazilian economy has experienced a substantial growth, which is in part associated with the growth of agriculture and other comparatively strong sectors, such as oil, mining, and, more recently, biofuels. Despite the recent

[27] A 'biome' is a "large, regional ecological unit, usually defined by a dominant vegetative pattern" (Wilgen *et al.*, 2008, p.337).
[28] Gross National Income Per Capita (GNI) in the range of $4,036 to $12,475 (World Bank, 2013b).

economic progress, though, Brazil still faces many structural problems such as poverty, which affects a high proportion of the population; unequal distribution of income, with concentration in large urban centres; high illiteracy rates; foreign indebtedness; and poor health standards.

Until the 1930's, the Brazilian economy was essentially based on the production and exportation of a few agricultural commodities (coffee, rubber, cocoa, and cotton), and the country depended largely on imported food to sustain itself. Brazil was, in fact, a large food importer up to the 1980's (Pereira *et al.*, 2012). By the 1990's, however, the situation had changed dramatically: the country became self-sufficient in agricultural goods and a major global player in food production and exportation.

Currently, Brazil is the world's largest producer of citrus fruits, soybean, and sugarcane, being also an important producer of coffee, poultry, corn, beef, and biofuels. Central to the expansion of agriculture in Brazil was the provision of subsidised financial credit, the rural extension system[29], and the consolidation of the National Agricultural Research System[30](SNPA), coordinated by Embrapa, the Brazilian Agricultural Research Organisation (Pereira *et al.*, 2012).

3.3.2 Embrapa and the recent development of the Brazilian agriculture

Embrapa is a state-owned research corporation that was formed in 1973 with the following institutional mission:

> *To generate and promote science and technology production in support of the national agriculture and agroindustry, for the social and economic welfare of the population, ensuring the preservation of the environment and*

[29] Mahaliyanaarachchi and Bandara (2006, p.14) define 'rural extension' as "an ongoing, non-formal educational process which occurs over a period of time and [...] leads to improve the living conditions of farmers and their family members by increasing the profitability of their farming activities". In Brazil, rural extension is developed by an array of professionals and institutions which work with families in rural areas and deal with problems in the rural environment.

[30] The National Agricultural Research System (SNPA, in Portuguese) consists of 17 public federal and state institutions and 70 universities that carry out research in agriculture and related areas.

rational use of natural resources. (Embrapa, 1988 - translated from Portuguese)

By the time Embrapa was created, a body of agricultural knowledge for tropical conditions[31] was not fully formed. Soils and weather in the tropics were seen as poor conditions for the production of the principal crops. The installation of Embrapa's specialised Research Units represented, therefore, an effort from the Brazilian government to put in place the necessary infrastructure to enable the selection and adaptation of imported agricultural technologies to the most diverse Brazilian biomes.

To help build Brazil's leadership in tropical agriculture, Embrapa has invested strongly in training researchers in centres of excellence worldwide. Currently, the company has 9,812 employees, of whom 2,431 are researchers (17% hold MSc degree and 82% PhD or Post-PhD). Approximately 75% of the staff is composed of administrative and support personnel, laboratories technicians and field/rural workers.

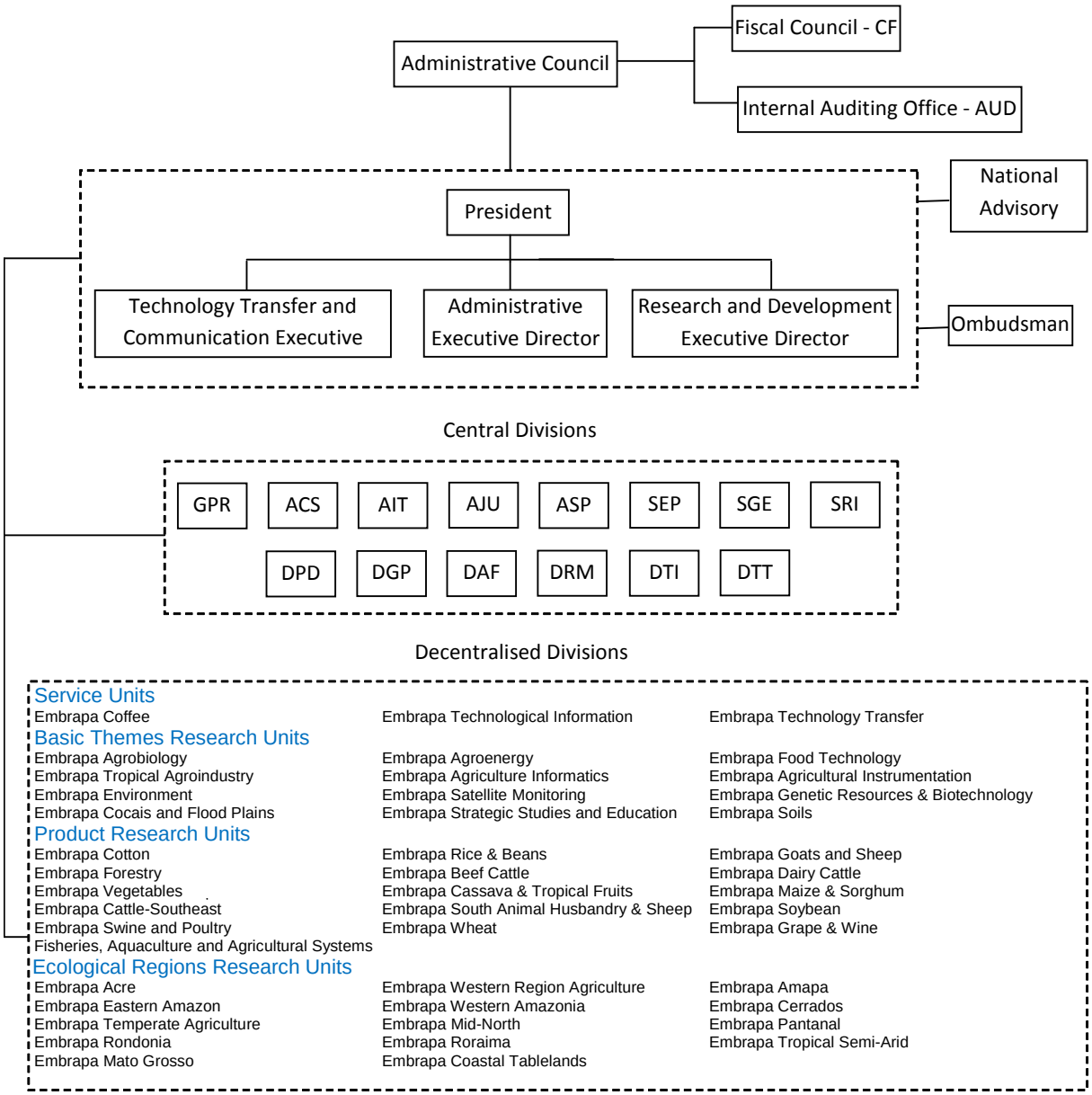
Embrapa has built a national and international reputation as a leading tropical agriculture research organisation. Currently comprised of 62 units (42 devoted to research, 5 to services, and 15 to administration), Embrapa is present in almost all Brazilian States, distributed over the five regions (**Figure 11**).

[31] Tropical agriculture occurs "between latitudes 23°N and 23°S, generally in acid, weathered, tropical soils of low fertility" (Pereira *et al.*, 2012, p.2).



Figure 11. Distribution of Embrapa's Research and Service Units. (source: Embrapa, 2013)
*Regions in Portuguese: *Norte* (North); *Nordeste* (North East); *Centro-oeste* (Middle West); *Sudeste* (South East) and *Sul* (South).

Embrapa's Research Units diverge in focus, according to which they are categorised as: 'Products', 'Basic Themes', and 'Eco-geographical regions'. 'Product Research Units' are devoted to research and innovation for the most important crop species used in Brazilian agriculture, including corn, wheat, rice, beans, soybeans, cotton, vegetables, and others. 'Basic Themes Research Units', on the other hand, are responsible for "developing and adapting knowledge, processes and innovations in biotechnology, genetic resources, advanced instrumentation, information technology, among others" (Lopes *et al.*, 2012, p.31). And lastly, 'Eco-regional Research Units' concentrate on adapting "innovations, technologies, information, and production systems that enable the sustainable use of natural resources of the different Brazilian biomes" (Lopes *et al.*, 2012, p.31). **Figure 12** presents Embrapa's organisational chart at the time of data gathering (in 2013, two new Service Units were created, which are not represented in the figure).



Legend:

GPR - President's Office; SGE - Secretariat for Management and Strategy; SRI - Office for International Affairs; SEP – Embrapa's Special Delevopment Program Executive Secretariat; ACS - Public Relations Office; AIT - Technology Innovation Office; AJU - Legal Advisory Office; ASP - Parliamentary Assistance Office; DPD - Research & Development Department; DGP - Personnel Management Department; DAF - Financial Administration Department; DRM - General Services Department; DTI - Information Technology Department; DTT – Technology Transfer Department.

Figure 12. Embrapa's organisational chart at the time of data gathering (as in 2013).

With SNPA-generated technologies, Brazil has solved century-old problems associated with the production, domestic supply, and insertion into international markets of foodstuff, fibres, and more recently, renewable energy. The growth of agriculture has been achieved with insignificant expansion of total agricultural areas, as **Figure 13** illustrates.

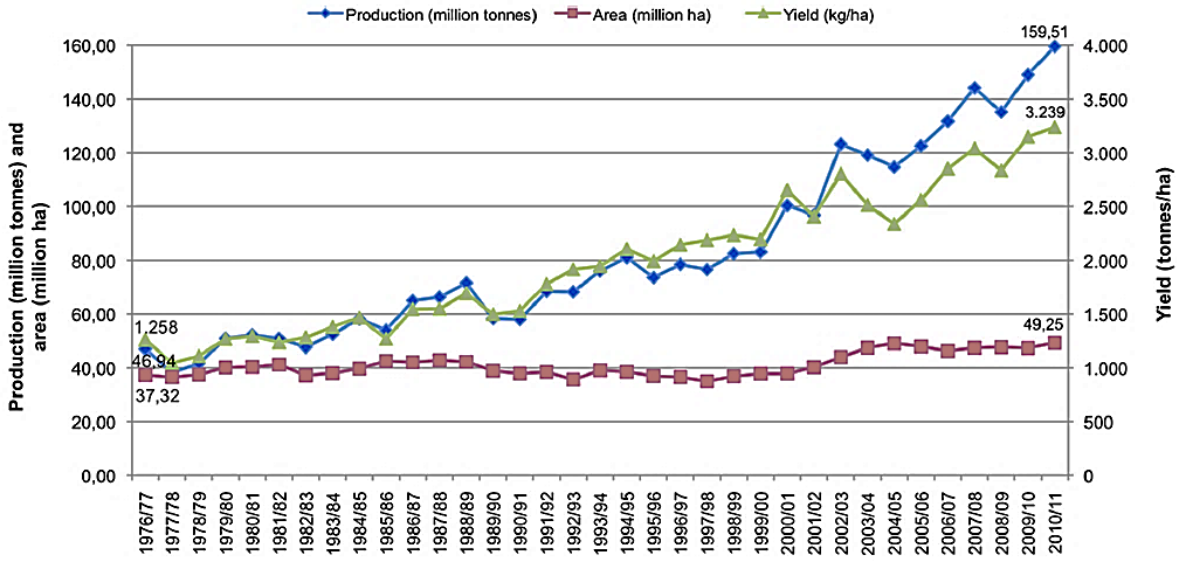


Figure 13. Evolution of grain and oilseed production, area and yield in Brazil (1976-2011). (source: Pereira *et al*., 2012, p.5)

Recent research on the impact of the technologies that Embrapa develops and transfers to Brazilian society demonstrated social profits of R$ 17.7 billion (Brazilian Reais), or US$ 7,5 billion (Embrapa, 2012). Thanks to the governmental Program for the Strengthening and Growth of Embrapa, the organisation has recently modernised its infrastructure and laboratories, set up new Research Units in agricultural expansion areas, as well as trained and increased staff numbers.

Over the last decade, Embrapa's international activities have intensified through the creation of the Virtual Laboratories Abroad (Labex) in partnership with the USA, France, Netherlands, England, and Republic of Korea. Business Offices and special projects are currently settled in Ghana, Mozambique, Mali, Senegal, Venezuela, and Panama. Next is a picture of the current international scope of Embrapa (**Figure 14**), showing Labex installations and technical collaborations with Southern countries.



Figure 14. International scope of Embrapa. (source: Agropolis International, 2012, p.12)

3.3.3 Embrapa's research outputs and the Open Access project

Agricultural science is arguably the most relevant contribution of Brazil to the advancement of knowledge. The numbers of publications from Brazilian authors in the field of agriculture has increased greatly in the last years: an advanced search in the *Web of Science* (http://apps.webofknowledge.com/) reveals that scientific production from Embrapa has more than tripled from 2002 to 2012, as **Figure 15** shows.

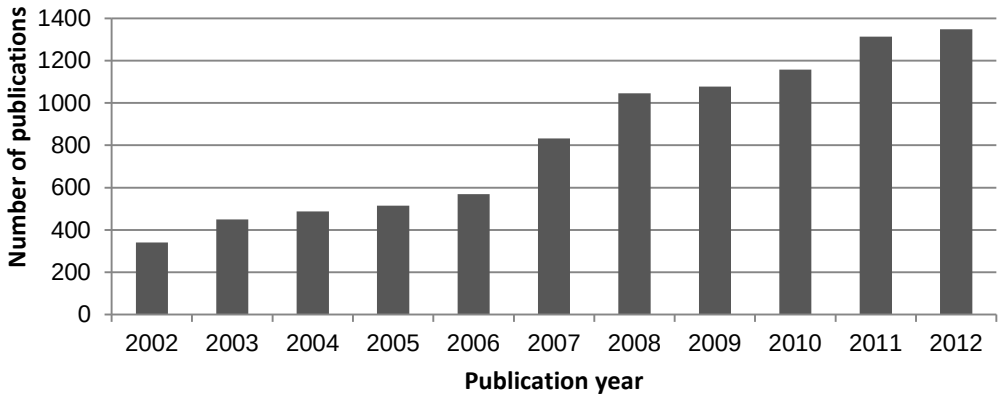


Figure 15. Embrapa's scientific production indexed in the *Web of Science*, 2002–2012.
(Equation used in the Web of Science Advanced Search: OO=Embrapa OR Brazilian Agricultural Research Corporation OR Empresa Brasileira de Pesquisa Agropecuaria OR Empresa Bras Pesq Agr OR Brazilian Agr Res Corp)

A thematic categorisation of Embrapa's scientific production, according to the *Web of Science*, shows that about 20% of publications from 2002 to 2012 have a multidisciplinary content. Results of this analysis are shown in **Figure 16**.

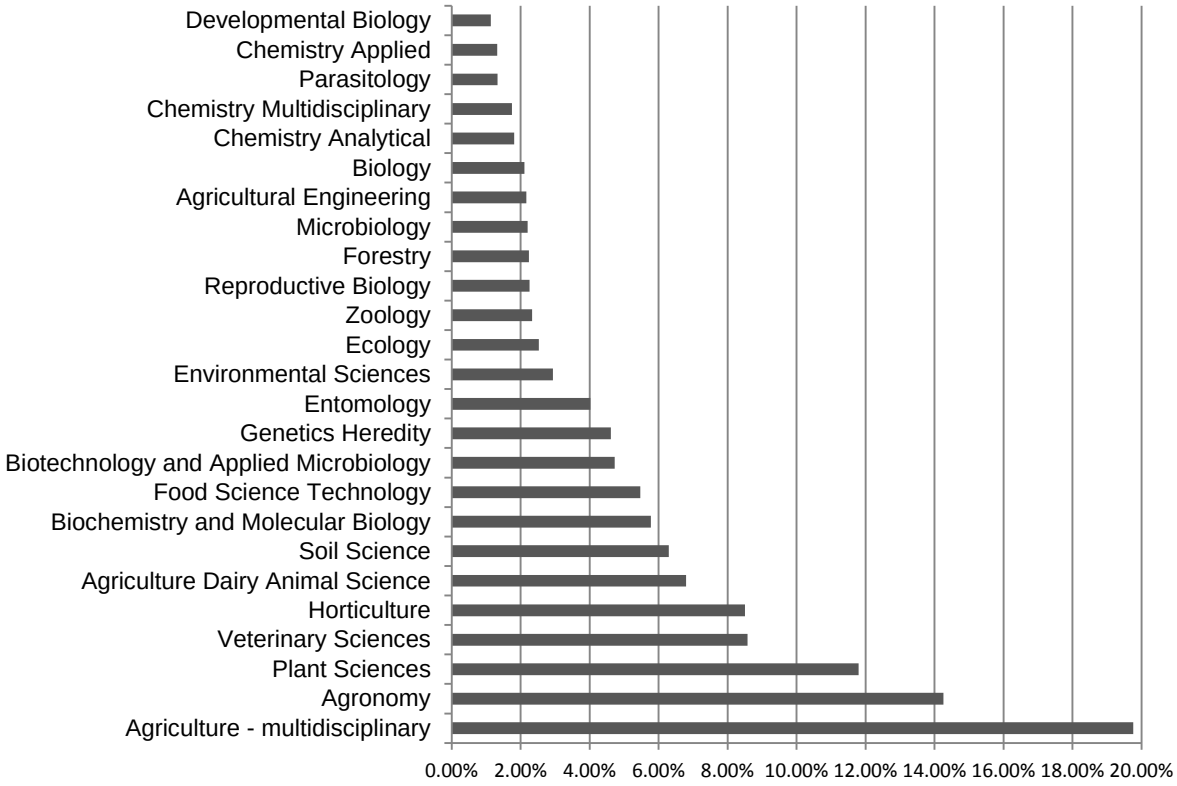


Figure 16. Themes of Embrapa's publications from 2002 to 2012, in the Web of Science. (Percentages are out of the total number of 9,137 publications)

It is estimated, however, that a significant part of Embrapa's scientific production is not indexed in internationally relevant bibliographic databases such as *ISI - Web of Knowledge*. In order to improve the visibility and accessibility of Embrapa's scientific production, the organisation is seeking to implement Open Access strategies to scientific information management (Bertin *et al.*, 2010). Just like global tendencies, Embrapa is adopting both strategies to Open Access: the Golden Road, that promotes open access directly through the publishing of scientific journals edited in the organisation, and the Green Road, through self-archiving scientific publications in the institutional repository (Bertin *et al.*, 2010).

3.4 Approach to data gathering

Having presented important background information to the case study, the general approach undertaken for data gathering is explained in the following subsections.

3.4.1 Sample selection and characterisation

To better represent the reality of Embrapa and of Brazilian agricultural research as a whole, six different Research Units were selected to participate in this study, from three distinct States of the Federative Republic. Besides the six Research Units, three Central Divisions/Service Units were also involved in the study[32].

It was desirable that the research sample included researchers from different agricultural science sub-disciplines and varied levels of hierarchies and seniority levels. To achieve that, 'systematic sampling'[33] was carried out. The first names in the alphabetical list of researchers from each Research Unit were selected to compose the research sample. After being invited, however, some of the researchers were unable to take part in the research, in which case the next person in the list was contacted, and so forth. Besides twenty-one researchers, one knowledge manager and two information managers were also part of the sample, so as to achieve an understanding of the current organisational strategies of information and knowledge management.

Interviewees' first academic degree was mostly Agricultural Engineering (n=15) and Biological Sciences (n=3), other disciplines being Chemistry (n=1), Electronic Engineering (n=1), Food Engineering (n=1), Library and Information Science (n=1), and Computer Science (n=2). The three professionals who work as information or knowledge managers at Embrapa graduated in Library and Information Science or

[32] The list of Research Units and Central Divisions/Service Units consulted is not presented here to preserve anonymity of participants.
[33] Systematic sampling is "a sampling method that selects samples using a numerical method, for example the selection of every tenth name on a list" (Walliman, 2006, p.215).

Computer Science. A list of interviewees, showing their main academic background, gender, area of specialisation/interest, and years of work at Embrapa is offered in **Appendix I**.

3.4.2 Data gathering method

In-depth interviews, also known as 'conversational' interviews, or 'unstructured' interviews (Walliman, 2006) were chosen as the appropriate method for gaining the rich qualitative data required in this research. Through adopting an in-depth approach for the interviews, participants were allowed autonomy in discussing general topics, raising correlated issues, and answering in their own way to open-ended, probe questions. In contrast, an over-structured approach could inhibit responses or produce little of consequence.

A thematic interview guide[34] with broad, open-ended questions was produced with basis on the literature review. The interview schedule, however, was only used as a directional guide — not as a means of limiting new lines of thought during the interview — being particularly useful when conversation did not flow. Two broader topics were covered in the thematic interview guide: (i) interviewees' 'academic background and career at Embrapa'; and (ii) 'research culture and laboratory practices'. In line with the notion of science as a system which purpose is to produce knowledge out of a set of inputs — a premise from the theoretical framework of this study[35] — the second topic of the thematic interview guide was subdivided into the themes 'inputs to research' and 'research outputs and outcomes'. A pilot interview with a researcher from Embrapa's Labex in the UK helped refine questions and gain confidence for subsequent interviews.

[34] The thematic interview guide is presented in **Appendix III**.
[35] The theoretical framework was explained in section 2.5 of *Chapter Two*.

For ethical reasons, Informed Consent Forms [36] were used for ensuring that interviewees understood what it meant to participate in this study and decided about it in a conscious way. The Consent Form was part of a larger document, in Portuguese, containing also an information sheet, fully informing participants about: the purpose of the research; responsible investigators; the kind of data that would be collected; how data would be stored and used; confidentiality and privacy terms.

After scheduling the interviews and details being arranged with participants, interviews were carried out from 10th July to 25th August 2011. Most commonly, interviews were conducted in the interviewees' offices and lasted for about one hour on average. The interviews, which were conducted in Portuguese, were digitally recorded and subsequently transcribed verbatim. For analysis, transcripts were translated to English and entered into the qualitative data analysis software 'Atlas-ti'.

3.5 Approach to data management and analysis

This section explains the analytical framework and the procedures undertaken for data management and analysis.

3.5.1 Main analytical framework

Soft systems thinking and, particularly, the Soft Systems Methodology (SSM) of Checkland (1981) represents the main philosophical and analytical framework of this investigation. A flexible use of SSM was adopted, to allow in-depth learning and appreciation of the holistic and meaningful characteristics of the problem situation within its contemporary real world context.

Technically, SSM was used as a learning- and theory-generating tool [37]. Here, the methodology serves as a point of reference to make sense and cope with the

[36] A version, in English, of the Informed Consent Form is offered in **Appendix IV**.
[37] As in reference to the classification of SSM uses in scientific investigations identified by Rose (1997).

complexity of the problem situation being investigated, and not as a recipe to be followed — a use that was, in fact, encouraged by Checkland (1999). Acting to improve or intervening in the problem situation, however, was beyond the academic focus of this study.

Soft Systems Methodology does not prescribe a particular data analysis method. It is implicit, however, that 'thematic analysis' must follow, which Braun and Clarke (2006, p.79) summarised as "a method for identifying, analysing and reporting patterns (themes) within data". One of the advantages of thematic analysis is its flexibility, as it comprises a foundational method for qualitative analysis that can be applied across a range of epistemological and theoretical approaches (Braun and Clarke, 2006).

In this thesis, data analysis followed an 'inductive thematic coding approach', as elaborated by Boyatzis (1998). Interview transcripts (already translated into English) were read thoroughly before coding, to gain a global perspective of the data. After that, the passages of text that exemplified similar ideas or patterns of experience were identified, as related to the research questions. The several passages were then linked together under the same description — a provisional code. Initial codes were grouped into a smaller number of themes and sub-themes.

After several cycles of reading transcripts and combining, splitting, or moving themes and codes, a final version of the codebook was obtained (**Appendix V**). The whole process of analysis was supported by the software Atlas-ti, which facilitated working through the interview transcripts, underlining, defining coding rules and themes, and writing comments on the material.

3.5.2 Levels of granularity

As previously mentioned in *Chapter One* (section 1.3) and reinforced in *Chapter Two* (section 2.5), the problem situation was investigated at two different levels of granularity. Complying with the systemic principle of this study, these were named the 'macro-' and the 'meso-level' of analysis.

The dynamics of the wider agricultural research system in Brazil comprised the 'macro-level', while the local practices and culture of agricultural knowledge production at Embrapa represented the 'meso-level'. Each systemic level was taken as

embedded into the other, and both were considered in the context of information governance. The two levels of granularity were illustrated in the rich pictures offered in **Figure 1** (pre-analysis), in the introductory chapter, and **Figure 18** (post-analysis), in *Chapter Four*.

3.5.3 Validation of the data analysis

In order to verify, confirm or complement the main themes and codes identified in the data analysis, a stage of validation of findings was performed. A return to Embrapa in the period of 10th July to 20th August 2012 allowed consultations with five additional researchers. The validation took the form of informal conversations covering the main themes that emerged from the data analysis. A list of the researchers consulted in the validation of the data analysis, including their academic background, gender, area of specialisation/interest, and years of work at Embrapa is offered in **Appendix II**.

For the validation stage, 'snowball sampling' was used — a technique "where the researcher contacts a small number of members of the target population and gets them to introduce him/her to others" (Walliman, 2006, p.79). The process started by selecting one researcher, at random, to participate in the stage of validation of findings. This person helped identify another researcher who would potentially be interested in taking part of the research; then, the second person suggested another name and so forth. As a result of the snowball sampling technique, five agricultural engineers took part in the validation of the data analysis.

The similar academic background of participants in the validation stage was not considered restrictive, since it reflects the composition of Embrapa's research team and is aligned with the configuration of the main sample, which contained mostly agricultural engineers (more than 70%). Besides, in terms of the range of specialist areas, participants in the validation stage were still very diverse and representative of the reality at Embrapa.

Data obtained in the validation stage was analysed according to the same procedure described in section 3.5.1. The broad themes that emerged in the data analysis were reinforced by participants in the process of validation of findings. That is, no new themes or codes emerged in the validation process. Essentially, conversations with researchers confirmed that the issues identified do indeed illustrate their perceptions

on agricultural knowledge production at Embrapa. However, because the sample was smaller, not all codes and subthemes from the main interviews surfaced in the validation phase, which was already expected. Quotes obtained from the conversations in the validation process are presented throughout *Chapter Four*.

3.6 Summary

This chapter has presented the philosophical underpinnings of this research, introduced background information to the case study, and the methodological approach undertaken for data gathering and data analysis.

After a brief review of research traditions and philosophies, with focus on the 'quantitative *vs.* qualitative', the 'positivist *vs.* interpretivist', and the 'hard' *vs.* 'soft' divides, the chapter introduced soft systems thinking as the main philosophical underpinning of this research. Then, the methodological approach to data gathering was detailed: systematic sampling being used to select twenty-four employees (twenty-one researchers) from different backgrounds, varied levels of hierarchies and seniority levels; and in-depth interviews undertaken so as to gain the rich qualitative data required in this research. Ethical aspects, involving confidentiality and privacy issues, were discussed next.

The chapter shifted, then, to present the procedures adopted for data analysis. Soft Systems Methodology (Checkland, 1981) was depicted as the main analytical framework of this study, adopted in a flexible way — as a learning- and theory-generating tool. After that, the different levels of granularity ('macro' and 'meso') in this study were explained. Thematic coding followed Boyatzis's (1998) approach, with Atlas-ti being used to facilitate working through the interviews' transcripts (translated from Portuguese), underlining, defining themes and coding rules, and writing comments.

Finally, the chapter detailed the validation of the data analysis, undertaken so as to verify, confirm or complement the main themes and codes identified in the data analysis. Validation of findings involved consultations with five researchers, selected through 'snowball sampling'. Participants in the validation stage were also diverse in terms of backgrounds, hierarchy and seniority levels.

Chapter Four. FINDINGS

Someone should be studying the whole system, however crudely that has to be done, because no gluing together of partial studies of a complex nonlinear system can give a good idea of the behavior of the whole.

(Gell-Mann, 1994, p.xi)

4.1. Introduction

The analysis that follows meets Research Objective 1 ('To determine the key macro-properties, the values and forces that govern the Brazilian agricultural research system, from the perspective of a public research institute') and Research Objective 2 of this thesis ('To explain the agricultural research culture, as perceived by researchers working in a Brazilian public institute').

The basic model of a system — that of 'inputs' being transformed into 'outputs' — is used to guide the narrative in this chapter. Emerging from the data gathered in the twenty-four in-depth interviews and five validation meetings, the broad categories of inputs to agricultural research were found to be 'physical', 'financial', 'human', and 'information resources', while 'information' (-as-thing, -as-process, and -as-knowledge) represents the main output of the system, which then may be employed to generate new technologies or agricultural processes (**Figure 17**). The main headings in this chapter correspond to these empirically obtained categories of inputs and outputs.

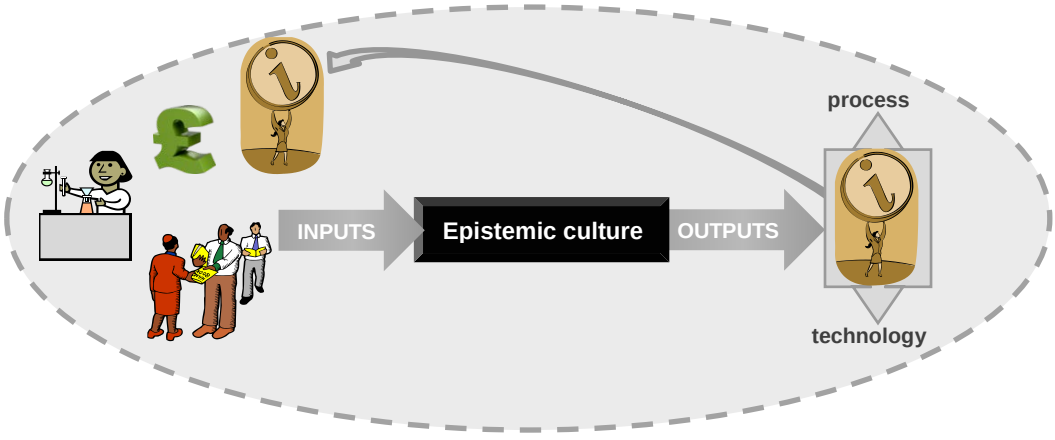


Figure 17. Agricultural research portrayed as a system.

Under each heading, issues are discussed from broad to specific, as expected from a holistic perspective. In systems terms, macro-properties of the wide agricultural

research system in Brazil are presented first, and then tracked down to the meso-episodes of the social and cultural life of agricultural researchers at Embrapa. A foreword is necessary, however, in relation to an important finding from the meso-level of analysis, which follows.

4.1.1. A foreword on the typology of agricultural research cultures

While analysing agricultural research from a 'meso' perspective, different cultures of knowledge production came to light, as a function of the different loci of experimentation in agricultural research. The following terms were then adopted to distinguish the different epistemic cultures: (i) *in situ* research, for when experiments are mainly developed in the field (that is, when natural phenomena are examined exactly where they occur); (ii) *in vitro* research, for when experiments are developed in the laboratory or greenhouse (phenomena are analysed in artificial, controlled environment which recreates natural settings); and (iii) *in silico* research, for when research activities are performed on the computer. This terminology is adopted throughout this chapter and in the rest of the thesis.

4.1.2. Chapter outline

This chapter begins by presenting participants' representations of the nature, the epistemic objects [38] , and the beneficiaries of Brazilian agricultural research (section 4.2). The remainder properties of agricultural research, at both a macro- and a meso-level of granularity, are discussed following, in relation to each class of inputs to (or outputs of) agricultural research. Thus, findings related to the physical settings and resources which are required in the process of agricultural knowledge production are examined in section 4.3. The subsequent section focuses on financial resources as inputs to agricultural research (section 4.4). Next, section 4.5 reports on human

[38] Epistemic objects are the scientific objects; those which are being scientifically explored and in the process of being developed. Epistemic objects are characteristically open, question-generating, complex, and perpetually incomplete (Knorr-Cetina, 2008).

resources and related issues. Findings concerning the issue of information as input to agricultural research are presented in section 4.6. Then, the subsequent section concentrates on the scientific outputs of the agricultural research system (section 4.7). Lastly, a summary of the chapter and a rich picture of the 'structured' problem situation (post-analysis) are offered (section 4.8).

4.2. Focus and beneficiaries of agricultural research

In this section, macro- and meso-observations concerning the nature, the focus, intended outcomes and beneficiaries of agricultural research are presented. To preserve anonymity of participants, as explained in *Chapter Three* (Research Methodology), pseudonyms are used when referring to or quoting individual interviewees.

4.2.1. Macro-representations of agricultural science: a systemic, application-oriented research framework

Participants of this study portrayed agricultural science as being a broad and diverse research framework. In line with that, the term 'agricultural science' was described as an overarching term that encompasses different disciplines, specialist areas and sub-areas which altogether influence the activity of agriculture. Owing to this characteristic, researchers referred to agricultural science as a 'systemic' science, or a "science that influences its own subject area — which is agriculture — in important ways" (Corey, plant geneticist [39], 2011). Basically, this occurs through the development and dissemination of new technologies and alternative agricultural production systems.

Given the broad scope of agricultural science, each researcher had a different perspective on the context and boundaries of the domain. It can be said, however, that agricultural researchers' concerns converge towards understanding complex natural

[39] A short explanation on the interests of each specialism mentioned in this thesis is presented in **Appendix I**.

systems and balancing food production with environmental constraints. Angelica (natural resources scientist, 2011) attempted a broad definition:

> *Agricultural research activities cover entire production and supply chains — from 'farm to fork' — taking into account particular social, economic, and environmental contexts.*

'Focus on societal impact' is a long-standing value in agricultural research. As a matter of fact, the real needs of farmers and the national market have oriented agricultural research since its early days in Brazil, as described by Luke (genomics/proteomics scientist, 2011), a researcher at Embrapa for over thirty years:

> *Since the 1970's, the recommendation from research managers was that our work should be well-grounded in the real needs of Brazilian agriculture.*

Luke (genomics/proteomics scientist, 2011) recalled that an orientation towards application was already underlined in the earliest mission statement of Embrapa. As documented in the First General Strategic Plan of Research, Embrapa's mission was defined as being:

> *To generate and promote science and technology in support of the national agriculture and agroindustry, for the improvement of the social and economic welfare of the population, through environment preservation and the rational use of natural resources. (Embrapa, 1988, p.23 - translated from Portuguese)*

Rather than focusing on theory development, agricultural research is driven by the need to solve practical problems, which is evident in process of research agenda setting at Embrapa (explored later in section 4.4.2), but is also a continuous concern. Madeline (genomics/proteomics scientist, 2011) explained that farmers and agents of production and supply chains are constantly reporting problems to the organisation and research activities being planned to provide feasible solutions. In a certain way, there is a relationship of demand and supply, as she explained:

> *My fellow colleagues who work in the agronomic part of agricultural research have far more contact with local communities, because there is a clear relation of supply and demand, selling and buying stuff. In some cases*

> *research is done alongside farmers. (Madeline, genomics/proteomics scientist, 2011)*

Michael (plant pathologist/biological control, 2011) illustrated the focus on application with an example from organic agriculture[40]. Given that the use of synthetic pesticides is not acceptable in this production system, whenever a new problem affects a certain crop, researchers are notified and research activities are prompted to respond to that real world need of farmers. In this case, research would attempt the use of beneficial living organisms or other natural mechanisms to prevent and control the infestation or disease — which is actually now the object of study of 'biological pest control', an area of specialisation in organic agriculture.

Identifying the real needs of farmers and developing suitable solutions are not always straight-forward tasks, Lindsay (molecular biologist, 2011) argued. To do so, it is of paramount importance to observe the constraints (of all kinds) in the context they operate within — such as the lack of skilled labour or training, outdated production techniques, infrastructure problems and financial issues they may be facing (Lindsay, molecular biologist, 2011). Eric (natural resources scientist, 2011) provided the following example of how this had played out in practice:

> *There was this situation once, when Embrapa developed a new variety of cassava and offered it to local farmers. Soon, researchers realised that the variety they were planting before was far superior. It is not that our research was poor, but the variety we produced required a series of procedures, defensives and stuff that local farmers could not afford. In those conditions, the variety that they had was more appropriate.*

[40] The International Federation of Organic Agriculture Movements (IFOAM) defines organic agriculture as "a production system that sustains the health of soils, ecosystems and people" (Paull, 2010, p.98).

Pure basic research [41] is severely limited at Embrapa. This was emphasised by researchers from different specialist areas, such as soil and plant nutrition, soil microbiology, plant genetics, plant pathology, and others. Researchers are continuously observing the production sector; in doing so, they are able to perceive and address the problems of farmers and agents of agricultural supply chains through research, as explained by Israel (soil and plant nutrition scientist, 2011):

> *We are instructed by research managers to try and keep close contact with the production sector. We observe what is happening there. What are the main needs? Then we try and adjust our research proposals to meet the demands that exist in the agricultural production sector. There is very limited room for pure basic research here, at least in the current configuration.*

Maryann noted that even when 'hard pure' [42] research is conducted at Embrapa, "there is an expectation that its outcomes will play a part in the solution of practical problems in agriculture" (Maryann, soil microbiologist, 2011). This was corroborated by Corey (plant geneticist, 2011) who, besides being a long-standing researcher, has also occupied several managerial positions during his career at Embrapa:

> *Our focus is on the real needs of society. That's why we do research foresight and strategic planning. We cannot abandon basic research, but we cannot be equally restricted to it. […] We can and should do basic research whenever it is expected to contribute to the solution of current or future practical problems. And this is of paramount importance for the organisation.*

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[41] Pure basic research is curiosity-driven, "undertaken primarily to acquire new knowledge for its own sake" (Salter and Martin, 2001, p.510). In other words, pure basic research is developed without any particular application or use in view.

[42] The 'hard pure' disciplinary grouping of Becher (1987) produces cumulative and atomistic knowledge, is concerned with universals, quantities, and simplification, and result in discovery/explanation. The 'hard applied' disciplinary grouping, on the other hand, is concerned with the mastery of the physical environment, generating purposive and pragmatic knowledge, and resulting in products/techniques.

4.2.1.1. Meso-level considerations: different outcomes and types of knowledge

In the data analysis, this was the point where the first evidence for the existence of different cultures of agricultural knowledge production was found. Although from a macro-perspective agricultural research might be strongly oriented towards application, differences were found with regards to the outcomes and types of knowledge produced by *in situ*, *in vitro*, and *in silico* research.

A strong link was found between the site of experimentation and the types of outcomes research typically produces: *in situ* research, for instance, is mainly directed towards the development of new agricultural processes, followed by new products. In fact, agricultural researchers whose work primarily takes place in the field are more concerned with applied knowledge as an outcome of their research. The following comment by Maryann (soil microbiologist, 2011) is illustrative of *in situ* research that aims at the development of novel agricultural processes:

> *My research usually focuses on concrete, practical and immediate problems in agriculture, so the most common outcomes are agricultural processes, such as the development and recommendation of a new way of planting, irrigating, fertilising or managing the soil, so as to minimise the occurrence of a certain plant disease.*

As regards the potential outcomes of *in vitro* research, they can be characterised as basic knowledge, which can further be conveyed into a new product or process. For instance, Alicia, a plant pathologist whose research involves molecular studies in the laboratory, stated that her research usually generates fundamental scientific knowledge, with potential of application in new technologies/products (Alicia, plant pathologist/molecular mechanisms of tolerance to stress, 2011). A further instance of this was presented by Alan (plant pathologist/molecular plant-pathogen interactions, 2011), who also develops *in vitro* research:

> *There is the expectation that a patent could be achieved, but the main objective in my research is to extend the knowledge in this research field. What my research basically produces is fundamental knowledge.*

In silico research, for simulating field or laboratory conditions, has the potential of producing varied outcomes (Frederick, plant pathologist/computational modelling, 2011).

4.2.2. Increasing complexity of epistemic objects as a macro-development

An increasing 'complexity' of the research problems being addressed was emphasised by interviewees (both researchers and information and knowledge managers) as an emergent phenomenon in Brazilian agricultural research. Objects of investigation appear to have become more complex over time, introducing increased complexity into the whole process of agricultural knowledge production:

> *The kinds of problems raised by the agricultural production sector have changed in the last thirty years... The organisation is adjusting to provide answers to these new, complex demands. (Michael, plant pathologist/biological control, 2011)*

To illustrate the growth of complexity in agricultural research, Corey (plant geneticist, 2011), who is an experienced researcher, gave a short historical account. He said that, forty years ago, Brazil needed to import food to sustain its growing population. The initial challenges in agricultural research were then, the mastering of natural systems, and the selection and adaptation of imported technologies and cultivation systems to the most diverse Brazilian biomes. In the 1970's, the priority of agricultural research was 'technology diffusion', which occurred in two instances: first, with the transfer of technology from developed countries to experts in Brazilian agricultural research institutes; and second, with the transference of knowledge and technology to local farmers through technological packages (Corey, plant geneticist, 2011). Another researcher commented on his involvement with technology diffusion in the 1970's:

> *Besides doing research, I was also responsible for transferring results and technologies directly to farmers. It was the time of the technological packages, which included all information farmers would need for a given crop production. (Luke, genomics/proteomics scientist, 2011)*

Continuing with his historical account, Corey (plant geneticist, 2011) explained that the first phase in Brazilian agricultural research was marked by rapid scientific development and concentrated effort on technology transfer, resulting in impressive

growth of the national agriculture, in terms of efficiency and productivity. In that period, agricultural research shared a similar set of values with industry; it relied heavily on quantifiable empirical data, on methodological rigour, and was mainly focused on accuracy and objectivity. Like an 'economy of scale', yields and productivity gains were the main goals of agricultural research (Corey, plant geneticist, 2011; Luke, genomics/proteomics scientist, 2011).

By the 1980-90's, the Brazilian agriculture industry had evolved so much that the country transitioned from the status of food importer to become one of the largest players in the global food market[43] (Luke, genomics/proteomics scientist, 2011). At the same time, the epistemic objects of agricultural research began to diversify, including interests as varied as productivity growth, plant and animal pathology, food technology, and biosafety of humans and the environment. Answering the challenges presented by the national and global markets became far from straightforward and the principals of an economy of scale started to shrink in the process of agricultural knowledge production. Corey (plant geneticist, 2011) described these as 'second generation' research problems and heralded something akin to a paradigm shift in Brazilian agricultural research:

> *The first challenge we had was surpassed: we learned how to manage natural systems and turn them into agricultural systems. In the subsequent phase, challenges in agricultural research were not simply technological anymore. I like to call them 'second generation' problems: a range of complex problems which were brought about with the globalisation phenomenon.*

Corey (plant geneticist, 2011) associated the challenges faced in the second phase of agricultural research in Brazil with the position the country had achieved as one of the

[43] Researchers credited the quick progress of agricultural research in Brazil to the early focus on personnel training, with undergraduates being hired by governmental institutes and offered opportunities to study in renowned universities across the globe. The rationale being that when those researchers returned to Brazil, they would bring along expert knowledge and a range of different perspectives, representing the most prominent schools of thought in agricultural science.

biggest producers of grain, meat, and energy in the global market. He provided an example of this with beef cattle research:

> *Brazil is a big meat exporter and nowadays the international market is very demanding and rigorous regarding meat safety and quality assurance, which consequently demands more from agricultural research. (Corey, plant geneticist, 2011)*

Apart from the strict quality and safety standards required by the international market, researchers at Embrapa indicated three other factors as accountable for the increasing complexity of objects of investigation in agricultural research: the growing world population, causing an ever-increasing demand for food; the increase in public awareness of the environmental impacts of agriculture; and the recent diversification of food habits and preferences by groups of consumers, generating new market niches. Jointly, these factors introduced uncertainty and tension into the process of agricultural knowledge production, as researchers began to face different and sometimes conflicting expectations from different stakeholders. Recent changes in the national legislation, for instance, have imposed many restrictions on research involving native species in Brazil, in order to protect them from uncontrolled commercial exploitation. The government, the private sector, and a series of environmental groups and legitimate stakeholders show conflicting viewpoints and interests, raising political, economic and social issues that influence studies with natural resources[44] (Franklin, plant pathologist/molecular plant-pathogen interactions, 2011). Another example is the conflicting demand for progressive development and use of technology in

[44] A similar situation was happening as I wrote this thesis. Different segments of society, the government, private and public sectors were engaged in a heated debate around the revision of the Brazilian Forestry Code in 2012. The adjustments in the environmental law that were being proposed would make it tougher on large agricultural interests by strengthening reforestation requirements along river banks and the Amazon region. The impact of the new code on agricultural research is that it would restrict the expansion of planted areas and the incorporation of new areas to agriculture. In other words, an onerous forest law could reduce agricultural production over the long term, thus presenting a current, complex challenge to agricultural research in Brazil.

agriculture, as opposed to the growing countermovement towards a more sustainable, healthy and locally based agriculture.

Increased complexity of the whole process of agricultural research was also confirmed in the validation stage as an important issue: “Doing research at Embrapa became a very complex process”, said Rosie (soil and plant nutrition scientist, 2012 - validation stage).

4.2.3. Beneficiaries

Four groups were identified as the main beneficiaries of the agricultural research system: farmers; agents of agricultural supply chains; rural technical assistants; and members of the research community. The research community are simultaneously beneficiaries of and actors within the system: they draw upon the knowledge produced as an output of the system and they are also the actors in the transformative process of inputs into outputs. The society as a whole, and organised groups such as environmental and support groups, policy-makers and research funders are not direct beneficiaries but important stakeholders in the agricultural research system.

Among all groups of beneficiaries, farmers are those whose needs are the key focus for agricultural researchers. To some extent, they can also be seen as actors, when directly engaged in the process of knowledge production, as described in section 4.5.5.

A positive relationship could be noted, however, between the type of experimental setting and the beneficiaries of its outcomes: *in vitro* research is usually targeted at the research community. Alternatively, when the field is the main locus of agricultural knowledge production (*in situ* research), or when research includes at least a phase of validation in the field, beneficiaries of research are mostly farmers, agents of production and supply chains, and rural technical assistants.

4.2.3.1. Conflicting demands from small farmers and large landowners

Farmers are the most important category of beneficiaries of agricultural research. Small farmers and large landowners, however, are quite different in terms of the

context they operate in and their particular needs and expectations, concerning the process of agricultural knowledge production.

Large landowners generally possess the skills, workforce, equipment, raw materials, and everything they need to keep up-to-date with the new technologies and to modernise production systems — embracing most recent recommendations from agricultural research. Small farmers, in contrast, operate in an environment of multiple constraints and engage heavily in the rural extension system[45].

Since small farmers produce on a small scale, they are less able to afford the latest technologies, expensive chemical agents, and to respond effectively to a crisis. Christian — a plant pathologist whose research involves engagement with small farmers — explained that the bulk of small farms' production is for subsistence and in some situations, farmers can barely provide for their families (Christian, plant pathologist, 2011). Small farmers are also the ones who demand the most from the rural extension system, requiring information and one-to-one support from rural technical assistants. They are, therefore, very demanding for agricultural research, requiring solutions to be tailored to their conditions — usually of very scarce resources:

> *Doing research with small farmers is a very complex thing, but we cannot look after the large landowners and forget small farmers. They cannot be excluded. (Eric, natural resources scientist, 2011)*

With Embrapa striving to provide equal support to small farming and agribusiness in their distinct and particular needs, agricultural researchers expressed a feeling of pressure when it comes to prioritising one or another's interests. Most of the participants agreed, however, that providing for both audiences is an obligation for Embrapa, as a public research organisation:

[45] 'Rural extension' is traditionally developed in Brazil by an array of professionals and institutions which work with families in rural areas and deal with problems in the rural environment.

> *Embrapa should not choose between agribusiness and small farming. Both are legitimate beneficiaries of agricultural research and we should provide for both of them. This is what distinguishes Embrapa from universities and other organisations; this is what makes it so relevant for the national agriculture. (Colton, molecular biologist, 2011)*

Given that large landowners are commonly knowledgeable enough to select, adapt and implement technologies, and, therefore, to find appropriate solutions to their problems, Christian (plant pathologist, 2011) argued, however, that the organisation should concentrate on the needs of small farmers. Rosie (soil and plant nutrition scientist, 2012 - validation stage) shared the same opinion as Christian, but recognised that this is rather a contentious subject.

4.3. Physical settings and resources as inputs to agricultural research

This section presents findings concerning the physical settings where agricultural knowledge production takes place and the physical resources which are required in this process (e.g. research facilities, equipment and materials).

4.3.1 Diversity of settings of knowledge production and cross-institutional research

'Institutional diversity' was highlighted by several researchers, while describing the process of agricultural knowledge production in Brazil. In their view, agricultural knowledge is produced in a variety of institutions — public and private research institutes, universities and organisations of different kinds.

Eric (natural resources, 2011) mentioned the recent consolidation of the 'National Institutes of Science and Technology' by the federal government to illustrate the organisational diversity in Brazilian agricultural knowledge production, whilst Corey (plant geneticist, 2011) acknowledged the National Agricultural Research System, established in 1992 by the Brazilian Ministry of Agriculture and comprised of organisations of varied natures and businesses, as demonstrative of the diversity of institutions involved in agricultural knowledge production in the country. Indirectly, these sites connect with each other via a network of research projects set up to respond to issues of current and common interest. Eric, for example, emphasised that

natural resources' projects are usually developed in partnership with universities and other research institutes (Eric, natural resources scientist, 2011).

Matthew (plant geneticist, 2012 - validation stage), who participated in the process of validation of the data analysis, emphasised the network of institutions that play a role in agricultural knowledge production:

> *Not only Embrapa, but universities and a range of private and public institutions play a role in agricultural knowledge production in Brazil. It is a network of institutions.*

'Cross-institutional networks' are, indeed, a constitutive feature of contemporary agricultural research in Brazil. Certain networks comprise dozens of organisations, as exemplified by Angelica (natural resources scientist, 2011):

> *We built a network of 27 organisations, including several of Embrapa's Research Units, universities, and other research institutes. [...] It is a network project, involving many organisations and covering the national territory.*

Differences were found at a meso-level of analysis, though. *In silico* research normally involves a wider array of institutions on a single research project than does *in situ* or *in vitro* research. For Frederick, a plant pathologist whose research involves computational modelling, the chief factor for this is the use of modern technology, through which geographic barriers to collaboration are eliminated — virtual experiments are developed in the computer and large datasets easily shared among specialists, regardless of institutional links. He exemplified by mentioning the range of organisations involved in one of his projects: agricultural and livestock defence agencies, the agricultural R&D institute of the State of Bahia, the Cuban institute of research on tropical fruits, the University of Cambridge and Rothamsted Research (Frederick, plant pathologist/computational modelling, 2011)

4.3.2 Organisational issues in relation to physical resources

As previously mentioned (section 3.3.2, *Chapter Three*), Embrapa is organised as a large network, composed of 47 decentralised units distributed across the several regions of Brazil and classified as Service Units, Research Units of 'Products',

Research Units of 'Basic Themes', and Research Units of 'Brazilian Ecological Regions/biomes'. The researchers highlighted, however, that though part of a single organisation, such diverse Research Units resemble different organisations, diverging not only in focus, but in culture and context, which adds complexity to the management of research resources. In other words, Embrapa is a highly 'heterogeneous' organisation, in the sense that Research Units are representative of multiple realities, as explained by Eric (natural resources scientist, 2011):

> *Embrapa's organisational structure is very complex... The forty-two geographically dispersed Research Units are so diverse in terms of their characteristics, businesses and contexts in which they operate, that one could speak of each of them as separate research institutes in their own right.*

Thomas, who is an information manager at Embrapa, mentioned that the dispersion among divisions is so apparent that individual Research Units are usually viewed by the public as separate entities, overpowering the image of Embrapa, as a whole. With decentralised units having high levels of autonomy, the impact and the relevance of the overall organisation, as one, is reduced. "It is the phenomenon of Embrapa losing ground to its own decentralised research centres", said Thomas (information manager, 2011). The Research Units are also highly heterogeneous in terms of availability of facilities and other physical resources:

> *There are different realities with regards to infrastructure at Embrapa. Essentially, there are multiple realities here; the organisation is not homogeneous. (Thomas, information manager, 2011)*

While describing the physical settings where their work is developed, researchers reported difficulties with infrastructure across almost all Research Units represented in the research sample. Problems of infrastructure are usually related to the lack of equipment or deficient maintenance of laboratory facilities, as explained by both Franklin (plant pathologist/molecular plant-pathogen interactions, 2011) and Margaret (molecular biologist, 2011). Two other researchers who have had the opportunity of working in Research Units which are remotely located in the Brazilian territory mentioned problems with high-speed internet connection, communication and transport (Colton, molecular biologist, 2011; Eric, natural resources scientist, 2011).

Buying equipment and investing in research infrastructure can be a struggle, especially when there are no funds available, apart from the government budget.

Purchasing at Embrapa is a bureaucratic process: as a public organisation, this process is shaped by legislation, public policy, and internally by strict institutional regulations. The focus is usually on price over quality which, according to researchers, can compromise the research process. Michael (plant pathologist/biological control, 2011) commented that he struggled for years with equipping his laboratory and was only successful when he established partnerships with industry. Other researchers reinforced that acquisition of materials and equipment is facilitated when funds come from external entities. In some cases, project funds are paid into researchers own bank accounts or transferred to and administrated by research support foundations. In the opinion of interviewees, this facilitates the management, distribution and expenditures of resources and funds, making purchasing less bureaucratic and more efficient. Another way to overcome difficulties with physical inputs to research is by establishing external partnerships, as Luke (genomics/proteomics scientist, 2011) remarked:

> *My work demands state of the art equipment and fieldwork facilities, and since the Research Unit I work at will not provide me with all the facilities I need, I seek external partners.*

The need to share facilities and resources is, in fact, an important driver of collaboration in the context of a developing country. The following comment, by Adele (soil and plant nutrition scientist, 2011), corroborates this statement:

> *Because of infrastructure problems and the lack of important equipment, we depend on establishing research collaboration to carry out our research projects.*

A historic perspective on how the shortage of resources has progressively forged collaboration in agricultural research was offered by Jacob (plant geneticist, 2011). While moving from a reality of resource abundance to one of scarceness, networking became essential in agricultural research:

> *In the past, we had plenty of resources for research and we were completely capable of doing research on our own. We did not need many research*

> *partners... Research projects were directed towards solving specific problems in the interest of the researcher. There was little scientific interaction. On the contrary, nowadays one needs to work in partnership. There are limited resources and we depend on partnerships to do research. We moved from one extreme to the other! Resources were reduced, in every aspect, and I reckon that networking in research is an irreversible trend. (Jacob, plant geneticist, 2011)*

Adele (soil and plant nutrition scientist, 2011) pondered, however, that at the same time that struggles with infrastructure motivates collaboration, they might also hinder it. Although travel costs have reduced over the years and despite the technological solutions which have emerged, infrastructure and transport problems which occur in a developing country still make collaboration complicated in some areas. Besides, bureaucratic issues may impede collaboration with external organisations. Tiffany (plant geneticist, 2011), for instance, mentioned that Embrapa, as a public organisation, has difficulties with transferring resources and funds to a partner organisation in a research partnership.

In vitro researchers explained that, to overcome difficulties with research infrastructure, modern facilities, located in the most developed urban centres are being implemented as 'multi-user laboratories', so as to provide a larger group of scientists with access to state-of-the-art facilities. These modern laboratories are often certified by the International Organization for Standardization (ISO), and have already implemented or are in the process of implementing, Good Laboratory Practices (GLP).

The implementation of multi-user laboratories is seen by most *in vitro* researchers as a remarkable progress. This is because until recently, Alan (plant pathologist/molecular plant-pathogen interactions, 2011) explained, the laboratory was more of a marked territory, where every workstation, every piece of equipment was 'owned' by someone and facilities were not easily accessible. The 'owners' were generally those researchers who worked hard to build the facilities and, since maintenance was a struggle, they were not interested in sharing them. For Alan (plant pathologist/molecular plant-pathogen interactions, 2011), this cultural issue is still present in many Research Units:

> *I am in favour of multi-user laboratories — sharing common devices. But what still happens today in some Research Units is that you have multiple compartments within each Unit, with almost private laboratories.*

Adele (soil and plant nutrition scientist, 2011) clarified, however, that the organisation headquarters acknowledges this problem and has made efforts to minimise it. She exemplified this by mentioning a recent change in the way laboratories are managed: while in the past, most labs were coordinated by researchers, at the time of interviews this role was being transferred to laboratory analysts. These professionals support all researchers who use the laboratory, manage the laboratory, conduct experiments, and take care of all facilities:

> *If something needs to be fixed or if new equipment needs to be bought, it is their role to inform us about it, so the demand can be included in new research proposals. (Adele, soil and plant nutrition scientist, 2011)*

The impetus underpinning the designation of a lab coordinator who is not a researcher is to guarantee a more collaborative environment. Nonetheless, "cultural aspects have prevented multi-user laboratories to be fully internalised in the organisation", said Alicia (plant pathologist/molecular mechanisms of tolerance to stress, 2011). In her opinion, a cultural change is required if the laboratory is to become a collaborative environment: "It is a process", she said, "it takes time; but I feel we are evolving, though in a very slow pace" (Alicia, plant pathologist/molecular mechanisms of tolerance to stress, 2011).

4.4. Financial resources as inputs to agricultural research

In this section, findings associated with the processes through which agricultural researchers manage to obtain the necessary financial input to their research are analysed. Here again, issues are examined from a 'macro' to a 'meso' perspective.

4.4.1 Increasing competition for research funding

Researchers at Embrapa have to compete for funds, but that has not always been the case, according to interviewees. When Embrapa was created in 1973, a share of the public budget was allocated to the organisation. There were sufficient funds and resources for agricultural research coming from the government at that time and no

competitive process was in place to access these funds, as described by Ashleigh (soil and plant nutrition scientist, 2011):

> *In the 1980's, there was far more money for research than nowadays, so that we need not search for funds externally. Financial resources from the government budget kept us going.*

Over the years, as Embrapa grew in terms of numbers of researchers employed and its portfolio progressively diversified, the share of the public budget became insufficient to cover all research activities. With that, researchers began to look at alternative funding schemes by the Brazilian government and a variety of national and international bodies that offered financial support to agricultural research.

At the time of the interviews, most researchers relied on a combination of funds raised externally and internally, from Embrapa's government funded budget. Some of the national entities financing their work are: Cnpq (National Council for Scientific and Technological Development, Brazil), Fapesb (Foundation for Research Support of the State of Bahia, Brazil), Fap-DF (Foundation for Research Support of the Federal District, Brazil), Northeast Bank (Brazil), Vale Brazil (mining company), and Petrobras (governmental corporation in the oil, gas and energy sector). Internationally, researchers mentioned the following agencies: Cirad (Centre de Coopération Internationale en Recherche Agronomique pour le Développement, France), Rothamsted Research (UK), European Community (EU), Monsanto, INRA (Institut National de la Recherche Agronomique, Argentina), Rockefeller Foundation (USA), MIT Food and Agriculture Collaborative (USA), International Atomic Energy Agency (Austria), and the World Bank.

Securing public or private funds for agricultural research has turned into a highly competitive process. At Embrapa, thematic research calls (developed by the Department of Research and Development – DPD, in Portuguese) determine the allocation of public financial resources. In evaluating applications, criteria are mostly the same as those established by external funding agencies: the experience and competence of the project leader, in terms of scientific publications and citation records; the technical quality of the proposal; and the alignment between the proposed research and the organisational strategic plan (this last indicator being specific to Embrapa's system of public funds allocation). Despite similar criteria being

employed by Embrapa and external funding agencies, most researchers feel that external competition is tougher. They pointed out some reasons for that. For Maryann (soil microbiologist, 2011), difficulties with accessing external funds are due to the greater strictness of evaluation boards when assessing the merit of the research team:

> *I've tried to raise funds for my research with FAP-DF [Foundation for Research Support of the Federal District, Brazil] but without success. I think maybe because of the curriculum and experience of the research team.*

Early career researchers struggle the most with meeting the requirements of external funding agencies, given their limited research experience and reputation in the scientific community. Israel (soil and plant nutrition scientist, 2011) explained how this can turn into a vicious circle, impeding early career researchers to get inserted into the scientific community:

> *I have applied for external funds, but so far I've basically counted on Embrapa's funds for research. [...] Raising funds for agricultural research is a very competitive process, especially for early career researchers. Because in general, scientific record is what really matters... If you do not have reasonably thick curriculum vitae, it is very difficult to get research proposals approved. It produces a vicious circle, indeed. You don't get funds because you don't have scientific publications. And you don't publish because you don't have a funded research project. So, it's hard.*

Lindsay (molecular biologist, 2011) argued that some of the intended outcomes of *in vitro* research, such as technologies or patents — which take time and effort to be produced — are not as valued by external funding agencies as they should be:

> *They don't care whether your research has produced something practical, such as a patent; whether your papers are being read or not, or their impact... It is now possible to measure this, but most research funding agencies do not take this into consideration.*

Experience in teaching and supervising postgraduate students is also a common criterion for decision-making and allocation of external funds, which is disadvantageous for Embrapa's researchers, since the institution has no formal role in education or postgraduate training (Margaret, molecular biologist, 2011).

Finally, the fact that Embrapa has a share of the public budget is also problematic, when it comes to competing for external funds. Many funding agencies view the organisation as financially self-sufficient and view proposals from Embrapa unfavourably compared to other institutes competing for money. With some funding agencies, this is so problematic that researchers need persuasive arguments to even get their proposals considered, as explained by Angelica (natural resources scientist, 2011):

> *The National Council of Technological and Scientific Development (Cnpq) privileges universities' proposals over Embrapa's because they understand Embrapa has a guaranteed funding scheme from the government. And we really do. With other funding agencies, such as Fap-DF [Foundation for Research Support of the Federal District] it needs to be more of a lobby and convincing work, just so you can dig some space to submit a research proposal.*

The increased competition for funding causes significant tension in agricultural research. Some interviewees argued that research in certain fields should not be subject to competitive research funding — such as in genetic resources and biodiversity characterisation. Eric (natural resources scientist, 2011), for instance, understands that getting to know the national biodiversity is a matter of "national security" and that collecting, analysing and characterising national genetic resources should be a continuous process with guaranteed funds and support. Nonetheless, the same system of funding applies to *in situ*, *in vitro*, and *in silico* research.

4.4.2 Emphasis on research steering and priority-setting

As the number and the types of entities financing agricultural research diversified over the years, interest in steering and setting research priorities increased. This has caused research priority setting to grow into an intricate process, which comprises a system-wide feature of agricultural research — affecting *in situ*, *in silico*, and *in vitro* research to the same degree.

At Embrapa, research priorities are defined by means of a two-level strategy. At the organisational level, Embrapa's headquarters develop foresight studies, so as to identify topics for research, keep up-to-date with developments in the agriculture

industry, and resolve potential conflicts over priority-setting. Corey (plant geneticist, 2011), who besides being a plant geneticist is a veteran research manager at Embrapa, described the process of research foresight:

> *In this sort of exercise, people are invited to think ahead and consider: what a desired, long term scenario for agriculture would look like? In relation to the cultivation of soybean, for example, or agriculture in the Cerrados area (Brazilian Savannahs). The exercise is to try and imagine that.*

Results of the research foresight study are then complemented with any government requests — a process that culminates with the production of the General Strategic Plan of Research, the official document that guides research and development over a four-year period at the organisation. Government demands can include, for example, the development of social technologies to improve the quality of life of small farmers in a particular region of Brazil or contributions to government social policies, such as the 'More Food' or the 'Brazil without Poverty' programs[46], as Corey (plant geneticist, 2011) explained:

> *The General Strategic Plan of Research must reflect societal demands and support government social programs, such as the 'More Food' program of the Lula government. We have responsibilities in this context: we produce knowledge through research and we need to transfer this knowledge to the interested audiences. Government demands can be, for example, for social technology to improve the lives of small farmers in a given area of Brazilian territory. As a public institution, we usually need to respond to these very specific demands from the government.*

[46] The 'More Food' government program finances the purchase of tractors, machinery, agricultural implements, harvesters, cargo vehicles, construction of warehouses and silos, electric fences, genetic improvement, soil improvement, orchards and farm logistics management, such as computerized inventory, among other actions, as a way to provide the conditions to increase family farming production (Brasil, 2011). 'Brazil without Poverty' is a social program aimed at Brazilians whose family income is only up to R$ 70 per person. The objective is to improve the income and the well-being of vulnerable populations (Portal RIO+20, 2012).

In order to identify opportunities and topics where research could make a difference at the local level, Research Units conduct market research (consultations with beneficiaries of research) and environmental scanning. The process of priority-setting at the local level, which conforms to the General Strategic Plan of Research, results in the formulation of the Research Unit Plan (Christian, plant pathologist, 2011).

The process of research agenda setting at Research Units illustrates the strong orientation of agricultural research towards application (see section 4.2.1). In this process, the opinion of farmers is most valued. Madeline (genomics/proteomics scientist, 2011) highlighted the involvement of stakeholders in the process of research priority-setting at the Research Unit she works at:

> *Here at Embrapa Cerrados, we usually bring together farmers, producers of fertilizers and other agricultural inputs, industry and government representatives. We sit all of them in an auditorium and invite everyone to discuss research priorities for the upcoming years. This is how we perceive and prioritise demands.*

In the opinion of Colton (molecular biologist, 2011), since agricultural research is developed to solve real world problems, constant engagement with farmers is essential. This is how the organisation can keep informed of their needs:

> *One cannot define the relevant issues for agricultural research without keeping in close contact with farmers. Agricultural research needs to solve real problems. That is why I am interested in drought tolerance, disease tolerance and increased yield potential. These are all real world problems of agriculture. (Colton, molecular biologist, 2011)*

In-depth engagement with the beneficiaries of research is, therefore, an on-going concern at Embrapa — not just during the preparation of the four year Research Unit Plan — but so that the Research Unit might keep up-to-date with changes in its environment and in relevant production chains, and be able to spot new research opportunities:

> *The organisation gathers information about the market through consultations with farmers and agents of production and supply chains. Researchers, themselves, while doing research, work together with farmers who manifest their problems. (Maryann, soil microbiologist, 2011)*

The intricate process of setting research priorities at Embrapa means that researchers have limited autonomy in defining their own research agendas, as stated by Franklin (plant pathologist/molecular plant-pathogen interactions, 2011):

> *Here at Embrapa, we have no autonomy in defining and pursuing our own research interests. Everything needs to conform to the organisation's strategic plan.*

Andrew (plant geneticist, 2012 - validation stage) highlighted the recent thematic organisation of Embrapa's research portfolio as an important development. With that, a general perspective of the research portfolio has been achieved, helping identify potential gaps: "This is essential to make appropriate use of public funds and is being used to steer research in important topics" (Andrew, plant geneticist, 2012 - validation stage).

4.4.3 Intensification of research commercialisation

The availability of funds from industry and the private sector for agricultural research is steadily growing. A configuration known as 'joint scientific development', in which industry integrates the process of knowledge production, is increasingly common in areas such as food engineering, molecular biology, biological control of pests, and biofuels research (Michael, plant pathologist/biological control, 2011). Of all Embrapa's Research Units, 'Embrapa Tropical Agroindustry' and 'Embrapa Food Technology' possess a proportionately higher number of links with industry, thus receiving more financial input from the industrial sector.

Michael (plant pathologist/biological control, 2011) was among the researchers with industry partners. He has experience using industry funds to buy laboratory equipment and improve facilities and has raised more funds through providing services to industry than through Embrapa's governmental budget. He had just received a patent for a pest control product and talked about his contacts with three companies, to sell his product, including international organisations.

With industry and the private sector playing a growing role in the financing of research, the emphasis on technology generation, innovation and intellectual issues has intensified in agricultural research. One of the interviewees mentioned that agricultural researchers are ever more concerned with the generation of technology and patents,

as “commercial exploitation of research is being pursued side by side with knowledge production at Embrapa” (Franklin, plant pathologist/molecular plant-pathogen interactions, 2011). The very vocabulary of researchers is illustrative of the emphasis on the commercialisation of research products, as can be noted in the quote below:

> *We need to work with the several links of this production chain so that our main consumer — which we think is the shelves of the supermarket — may receive the products and offer them to the final consumers. (Angelica, natural resources scientist, 2011)*

The pressure to produce outcomes which can be commercially exploited is rapidly perceived by researchers who start working at Embrapa. Margaret (molecular biologist, 2011), who had been at Embrapa for seven years, pointed out this shift in focus from basic to applied research:

> *My interests were more focused on ‘pure’ basic research, before I started working at Embrapa, but I needed to change and begin working with more applied research. Embrapa is not interested in knowledge if it is not associated with technology generation and this is quickly made clear.*

Long-standing researchers reinforced that commercial exploitation of research is a recent pursuit of the organisation. Ashleigh (soil and plant nutrition scientist, 2011) explained that first projects of this nature are now in the completion phase:

> *I am now working on the generation of a new technology, which is basically what the organisation is demanding from us, researchers, in present times.*

Commercial exploitation of research is a contentious issue among researchers, though. Most criticisms are that the research activity and commercial development are antagonistic in practice; or that the organisation is unfit for this task. In order to overcome the last aspect, most Research Units have made efforts to create a commissioned sector and to develop the necessary skills to deal with intellectual property issues, as Adele (soil and plant nutrition scientist, 2011) noted:

> *Regarding technology generation, we needed to create an intellectual property centre, because this Research Unit was very weak in this topic. People didn’t know what to do regarding intellectual property and new technologies generation. This is not a problem anymore.*

A major criticism is that many of the questions driving *in situ* research have no potential of generating profit in return. Instead, it is largely focused on the needs of small farmers and local production systems, where profitability is limited. In these circumstances, the logic of making money out of research outcomes is not applicable (Christian, plant pathologist, 2011).

An undesirable development associated with the increased participation of the private sector in agricultural research is the organisation's limited control over the commercial exploitation of technologies generated in the research process, as explained by George (plant geneticist, 2012 - validation stage):

> *Some of the technologies we produce have great impact on the market. One cultivar of pepper was really successful: it is being planted in more than fifty hectares, which is a lot for peppers. But this cultivar was developed in partnership with a private company, and as determined in the contract of research and development, this company has the exclusive rights on the cultivar for the period of eight years.*

Interestingly, the opinion of researchers who develop *in vitro* and *in silico* research differed from that of *in situ* researchers with regards to private funding of agricultural research. Researchers who develop *in vitro* and *in silico* research are more concerned about the possibility of further reduction of the public budget for research and see the opportunity of raising funds with industry and commercialising research outcomes as a promising alternative: "the future in research funding", said Frederick (plant pathologist/computational modelling, 2011).

4.4.4 Pressure for accountability and research quality monitoring

The progressive diversification of entities involved in the steering and financing of agricultural research was accompanied by an 'increasing pressure for accountability in research'. The issue is not only about justifying how monies are spent in research, but also proving that intended outcomes are being produced, according to certain quality requirements. To cope with that, Embrapa has strengthened the mechanisms of quality control and assurance.

In fact, most researchers reported an increase of rigour in the process of research quality control at Embrapa. Ashleigh (soil and plant nutrition scientist, 2011) described

what used to be the only form of quality control of research projects at Embrapa in the past — a yearly report:

> *Formerly, there was hardly any control. The only monitoring mechanism was the annual research report, but I'm sure they didn't read all those reports as well…*

While in the past there was little interest in controlling the quality of research proposals and projects' execution, nowadays a mandatory process of quality monitoring takes place in each Research Unit. In support of this change, Internal Technical Committees (CTI, in Portuguese) were established in each Research Unit and made responsible for closely monitoring the progress of research projects (Ashleigh, soil and plant nutrition scientist, 2011). The increasing focus on quality monitoring was reinforced in the validation of the data analysis:

> *The monitoring of the research projects became a very solid and robust system at Embrapa. (Matthew, plant geneticist, 2012 - validation stage)*

There are two main practices of research quality control at Embrapa. The first one is an internal peer-review process of research proposals, before submission to an external funding agency. The process is entirely coordinated by the CTI, which nominates internal examiners to technically review and assess the overall quality of each research proposal. Alicia (plant pathologist/molecular mechanisms of tolerance to stress, 2011) highlighted the increased interest of research managers in monitoring the submission of proposals:

> *In the past, not even the research manager knew what was being proposed to an external funding agency. Now there is much more control: all research proposals are first analysed by the Technical Committee.*

In some Units, the quality assessment process of research proposals includes discussing research ideas in internal seminars and extended research groups, as stated by Margaret (molecular biologist, 2011):

> *It is mandatory here at this Research Unit that every research proposal is to be orally presented at the level of the thematic research group even before being submitted to the Internal Technical Committee. General strategy, collaborators, budget, everything is thoroughly discussed.*

Quality monitoring does not end after submission and approval of research proposals. The second level of research quality control occurs during the project's execution. Progress is monitored through the systematic presentation of technical reports and regular meetings with research peers and heads of research from the Research Unit and Embrapa's central departments. In this process, research projects are assessed in terms of targets and objectives achieved, and then scored according to the following: projects whose goals are being achieved as expected; projects whose goals surpass those expected; and projects where the objectives or the goals are not being achieved as planned. Project leaders are then issued with a report containing assessment comments and recommendations on any observed issues. About six months later, projects are reassessed to check whether the difficulties have been overcome. Maryann (soil microbiologist, 2011) commented on the strengthening of quality control measures at Embrapa:

> *Quality control of research has intensified in recent years; in fact, it is pretty intense at Embrapa. A committee from the central research department visits each Research Unit to monitor the progress of selected research projects. They want to know the current situation of the project; what percentage of the objectives has already been fulfilled, what is not going well, and why not? Everything must be justified. Apart from these meetings of progress monitoring, there is additional control through the delivery of management and technical reports, every four months. If you do not submit the report, funds are locked. So, control has really intensified.*

Processes and local practices of research quality control may vary slightly across Research Units. However, researchers were unanimous in their perception that quality control has intensified in recent years. In the Research Unit Adele works at, when a project's targets are delayed or when the project is really problematic, the CTI takes action to help reduce the problems as much as possible and closer monitoring of the project is inaugurated (Adele, soil and plant nutrition scientist, 2011).

In the opinion of most researchers, quality control is much more intense when funds come from the government budget administered by Embrapa than when they are obtained via private funding agencies, which illustrates the increased social pressure for accountability in research:

> *With other research funding agencies, there is no such direct action of progress evaluation. The only evaluation takes place towards the end of the project, with the elaboration and submission, by the project leader, of the final report. (Tiffany, plant geneticist, 2011)*

Thomas, who is an information manager, credited the advance in the process of research quality control at Embrapa to the recent development of dedicated information systems. He described how the entire process works, from the point of view of information systems:

> *The mechanisms of quality monitoring have improved. Currently, research reports are no longer mailed, as was done previously. Semi-annual, annual and final reports are submitted through an electronic system. After a research proposal is accepted, the project gets underway: the leader does the budgetary distribution, gets his resources and starts the project. Six months later, the system itself alerts the project leader that he needs to fill out the semi-annual report; that being done, research managers are notified. The report gets deeper in volume and depth of information over time. All history of negotiation between project leaders and managers is registered there, then, one can understand why and how a project yielded certain results. (Thomas, information manager, 2011)*

The information manager argued, however, that quality control at Embrapa is more focused on the monitoring of the research process — and particularly the expenditures — than on the quality of the results or products generated. In his opinion, monitoring of the quality of research results is unsatisfactory. Christian (plant pathologist, 2011) agreed with this and added that quality control at Embrapa could be improved, especially with regards to the management of research data:

> *Embrapa knows very well how to induce research projects and manage research funds — these are formally established processes. But when it comes to monitoring the real results and impact of accepted research proposals, procedures are incipient. All reports we produce, as research project coordinators, have more of a managerial content. It is more about what we've spent and less about what we've achieved. […] Research raw data is not recorded anywhere.*

Another instance of the current emphasis on the accountability of research is the competitive system through which the performance of Embrapa's Research Units is evaluated. This aspect is examined in the next section.

4.4.5 The competitive system of results evaluation and reward of Research Units

At the time of data collection, Research Units were assessed by Embrapa's headquarters on a yearly basis, as part of the corporate System of Results Evaluation and Reward, created in 1996. This analysis adopts three main criteria and several associated indicators, as explained by interviewees.

The first criterion is 'productivity', which is measured according to three indicators: efficiency in raising external moneys; productivity evolution; and technical efficiency. The second criterion is 'managerial quality', appraised in terms of: achievement of targets from the General Strategic Plan of Research and the Research Unit Plan; actions to improve management; partnerships established; and participation in international projects. The third and last criterion is 'satisfaction and impact', evaluated according to economic, social and environmental impact.

Ultimately, the analysis aims to assign each Research Unit with an Index of Institutional Performance (IPI, in Portuguese). For example, the indicator 'participation in international projects' is measured in terms of numbers of partnerships — through research projects, co-authored scientific papers, and missions of cooperation and business/technology transfer events — divided by the number of researchers at the Research Unit. In another example, the 'technical efficiency' is determined as a ratio of the annual production of a Research Unit (the numbers of technologies, products and processes developed, scientific papers and technical communications published, technology transfer and marketing actions) to the costs involved. The main result of the entire process is a ranking of Research Units, according to their IPIs, which is used to determine how funds for infrastructure improvements are to be distributed across the organisation, as explained by Eric (natural resources scientist, 2011):

> *If a Research Unit does not achieve or exceed established goals, it drops in the ranking and this influences the amount of resources and funds released to the Unit in the following year.*

A number of researchers interviewed criticised the System of Results Evaluation and Reward of Research Units, arguing that it fails to recognise the particulars of each Research Unit — the kinds of research they are commissioned to do, the types of outcomes their research usually produces, and how research outputs are usually communicated (Christian, plant pathologist, 2011).

Michael (plant pathologist/biological control, 2011) made the interesting point that, while some Research Units are more focused on hard pure research (such as Embrapa Genetic Resources and Biotechnology), others concentrate on hard applied research (e.g. Embrapa Vegetables). The first group of Research Units produces more scientific papers, while the second concentrates on technical and knowledge transfer communications. This fact was further corroborated by Luke (genomics/proteomics scientist, 2011) and Israel (soil and plant nutrition scientist, 2011).

By the same token, Eric (natural resources scientist, 2011) emphasised that the system of performance evaluation of Research Units does not take into account regional inequalities, which abound in Brazil. He went on to compare practical aspects of doing research on natural resources in two of the Brazilian States — São Paulo (in the Southeast region) and Amazonas (in the North region) — and argued that Research Units in the North region are always in a disadvantageous position:

> *Research is much more expensive at Amazon than in São Paulo. For you to go to a conference in Sao Paulo, or in the South / Southeast (as it happens to be the case with most major conferences), expenses are tremendous. For you to reach certain localities in the Amazon area it is very expensive, because distances are extremely large, and transport is precarious. So, this is what happens: as a researcher, you are forced to restrict your work to locations closer to Manaus, because you have no means to work in the rest of the state. While in a State like São Paulo, with four or five Research Units of Embrapa, distances are small and the researcher's job much easier. Then, research results in São Paulo are much more striking. That is why, in a comparative evaluation of the 42 Units of Embrapa, research centres in the Amazon are always badly positioned: from 38th place onwards. It is a very complex situation. (Eric, natural resources scientist, 2011)*

The immediate effect of using a unified set of criteria and a linear system of performance assessment across very diverse and heterogeneous research settings is

that it reinforces competition, instead of collaboration among Research Units, as stated by Christian (plant pathologist, 2011):

> *The current merit and reward system encourages much more of a competitive culture than a collaborative one. One Research Unit competes against the other, to be better positioned in the general ranking of Research Units.*

Corey (plant geneticist, 2011) asserted that the process of Research Units performance evaluation should not be comparative. He argued that simple exercises, such as monitoring the availability and cost of goods in the national market, give clear evidence of the quality of work Research Units have developed over the years:

> *The relevance of this organisation to the society cannot be measured in terms of scientific production. It is measured by the fruits we generate for this country. If you look at any production chain, you will get to see Embrapa's work there. Studies show that the price of groceries has dropped over the years in Brazil. This shows the impact of agricultural technology on people's diet; this is the impact of agricultural research. (Corey, plant geneticist, 2011)*

The interviewees remarked, however, that the organisation's headquarters were already sensitive to the problems deriving from the System of Results Evaluation and Reward of Research Units, and that an alternative scheme was under development at the time of interviews.

4.5. Research actors and human resources as inputs to agricultural research

In this section, issues related to the human resources of the agricultural research system are analysed: 'who' the research actors and the co-participants in the research process are, and how these are interrelated.

4.5.1 The changing profile of researchers and time pressures

Interviewees reported that the profile of the agricultural researcher has changed over the years, to cope with the dynamic and increasingly complex environment of agricultural research. Particularly, managerial and leadership skills are required, as

researchers embrace large network projects and face issues related to resources, processes and problem management, negotiation, risk and intellectual property issues, in the conduct of research.

In fact, most researchers mentioned projects, processes and problem management as critical skills in the contemporary profile of agricultural researchers. The following quote, by Angelica (natural resources scientist, 2011), is illustrative of the difficulties involved in conducting large network projects and the skills demanded of the research leader:

> *Projects of this scale are very difficult to conduct and demanding in terms of management and organisation. There are more than one hundred researchers working in this project and I, as the coordinator, need to provide for the whole group of collaborators, so that each one has the necessary resources and is able to develop their part in the research.*

Tiffany (plant geneticist, 2011) argued that the traditional education system does not cover the newly required skills that the agricultural researcher needs to develop. In particular, she emphasised the need for the development of management skills, which at the moment are being acquired through experience and observation:

> *In reality, a research project leader is someone who manages people, resources, and knowledge, so I think management skills are very important for contemporary researchers. However, these sorts of skills are not usually covered by traditional academic and scientific training. It is something we are forced to develop in practice. It's tacit knowledge. But I think this is increasingly important. (Tiffany, plant geneticist, 2011)*

Apart from the managerial and leadership skills mentioned above, Maryann (soil microbiologist, 2011) added that understanding the English language and being able to network with international research fellows and communicate results in English are desirable skills which confer competitive advantage to Brazilian agricultural researchers.

A growing role in technology transfer and technical assistance activities is also requiring additional skills of agricultural researchers, particularly those developing *in situ* research. This has intensified after the recent disassembling of the rural extension system, which led Embrapa to divide attention between research and

technical assistance to farmers. For Christian (plant pathologist, 2011), this was an unfortunate development:

> *In my opinion, the progressive weakening of the rural extension system was a pity. They had good penetration throughout the Brazilian territory and were capable of speaking directly with farmers. Embrapa, as a research institute, is not able to accomplish both jobs.*

Other researchers showed disapproval of the involvement of Embrapa in technology transfer and technical assistance activities. Franklin (plant pathologist/molecular plant-pathogen interactions, 2011) was one of them:

> *I think the role of transferring research results and technologies to farmers fits rural extension entities. Unfortunately, these entities were almost extinguished some years ago and now, in spite of efforts from the current government to strengthen the rural extension system, it is working poorly. With that, society started pressuring Embrapa to take on this role, but as a research corporation, Embrapa cannot and should not take this responsibility.*

The continuous chase for money, the growing complexity of research, and the multi-layered challenges researchers face nowadays were indicated by Alicia (plant pathologist/ molecular mechanisms of tolerance to stress, 2011) as the cause of the recent changes in the profile of agricultural researchers. She sees the new roles as taking time away from research.

These findings were corroborated in the validation stage. Megan (post-harvest physiologist, 2012 - validation stage), for instance, commented on the new roles researchers are being required to play:

> *Besides doing science, researchers nowadays need to communicate well with the several audiences; be skilled in projects, resources, people, funds and data management. It's just too much for a single person!*

As a consequence of the different activities and roles that researchers are now engaged in, there is limited time allocated for what they see as scientific activities, such as going to the laboratory or the field and developing their own experiments. Israel (soil and plant nutrition scientist, 2011), for instance, mentioned that almost

half of his time is lost with activities which are not related to research. Angelica (natural resources scientist, 2011) expressed dissatisfaction:

> *I miss going to my lab workbench, which is what I know best. Nowadays, I consider my job much more as a management position than a research job. [...] I can no longer go to the workbench. I have many students and I supervise my students, but you know... just occasionally I'm going to the lab.*

Not being able to go to the lab means fewer experiments conducted and fewer results to communicate, which Alicia (plant pathologist/molecular mechanisms of tolerance to stress, 2011) sees as detrimental for the advancement of research:

> *If I could, I would be in the lab eight hours a day, because this is what gives me pleasure. Besides, by doing this you will have more in return, because you are getting results, which are going to be published, disseminating knowledge. This is not the reality for the majority of us.*

Christian (plant pathologist, 2011) argued that the work overload hinders collaboration among Embrapa's Research Units and laboratories. He said that some laboratories are in such demand that it is easier to establish collaboration with external groups and universities. Franklin (plant pathologist/molecular plant-pathogen interactions, 2011) agreed that work overload, associated with the new roles researchers are playing, leads to difficulties in contributing to other colleagues' projects:

> *I would like to collaborate more in other colleagues' projects, but if I did so, I would not be able to accomplish my own work due to time constraints.*

The particulars of Embrapa, in relation to students' recruitment and technical support to research are presented in the next section.

4.5.2 Struggles with technical support and students' recruitment

Lack of technical support personnel was a common complaint of the interviewees. Jacob (plant geneticist, 2011), for instance, said that Embrapa "has a very large gap between the number of researchers and assistants". Israel (soil and plant nutrition scientist, 2011) corroborated this by saying that human resources at the organisation

are not well balanced and emphasised the problem of research assistants retiring and not being replaced.

Eric (natural resources scientist, 2011) explained that, as a research organisation, Embrapa is continuously focusing on increasing the numbers of researchers, so as to increase its research outputs. However, the shortage of technical and support personnel compromises research activities:

> *I believe the structure of this organisation is top-heavy: many researchers with little technical support. We do not have the necessary support for research, because when the company is hiring, there is a priority to hire more researchers. With that, there is a shortage of agricultural technicians, field personnel, lab technicians, etc... Field staff is a very serious problem, especially now that many of them are retiring or getting to an age where they cannot sunbathe every day. It is complicated. (Eric, natural resources scientist, 2011)*

Franklin (plant pathologist/molecular plant-pathogen interactions, 2011) explained, however, that the problem of technical support for research is not exclusive to Embrapa, but is a problem that universities also experience: postgraduate students are in fact their main workforce. By participating as teachers or associate researchers in postgraduate courses at local universities[47], agricultural researchers minimise the problem of technical support in the field and the laboratory.

Recruiting students is challenging for Research Units located in remote rural areas, however, where there is no university close-by. For this reason, Margaret and Madeline (respectively, molecular biologist, and genomics/proteomics scientist, 2011) argued that student recruitment is not a universal solution for technical support to research at Embrapa. Christian (plant pathologist, 2011) expressed concerns:

[47] Although Embrapa has no formal role in education, researchers are allowed to co-supervise postgraduates through arrangements and partnerships with local universities. Embrapa's researchers cannot be main supervisors, though, according to current norms.

> *This Research Unit suffers the most from the lack of technical support to research. Right now, my back is aching because I had to fertilise 200 plants and there was no-one to help me with that. I had to go and squat two hundred times, to have the service done. There is little support in the field, greenhouse, laboratory... So I think if you talk to ten scientists here, the ten will tell you that technical support is a serious problem in our Research Unit. We cannot accomplish many things because of that.*

Hence, Embrapa's Research Units are not only heterogeneous in terms of facilities and physical resource availability (shown in section 4.3.2), but realities are also multiple in terms of human resources and student recruitment capabilities. While some of Embrapa's labs and experimental fields have a number of associated technicians, in many others there is no technical support available. Michael (plant pathologist/ biological control, 2011), for instance, described his laboratory as being on a small-scale, basically used by two researchers and lacking some important equipment. Because there is no postgraduate course in Biological Pest Control around the city, he struggles with student recruitment. Other laboratories are far bigger, he said, with state-of-the-art facilities, plenty of technical support personnel available, and several associated researchers supervising dozens of graduate and postgraduate students. In Michael's opinion, an appropriate support and infrastructure help researchers increase their publications rates: researchers who work in these conditions, he said, "always win on the race for scientific publications, thus getting more recognition" (Michael, plant pathologist/biological control, 2011).

Difficulties with technical support and students' recruitment affect the three epistemic cultures, but *in situ* researchers complained the most about inadequate provision of agricultural technicians and field staff. The shortage of resources of all kinds, Maryann (soil microbiologist, 2011) argued, is a source of competition among researchers:

> *We need to compete for technical support, facilities, materials, but this happens basically because of the shortage of funds and resources.*

But competition is not the only cultural force in place. Collaboration, paradoxically, is a requirement in contemporary agricultural knowledge production.

4.5.3 The imperative for collaboration and the growth of multidisciplinarity

In order to cope with the complexity of nature, science has compartmentalised its interests into a series of categorised disciplines and specialised areas. Responding to this trend, additional levels of specialisation and sub-specialisation have progressively emerged in agricultural science (Colton, molecular biologist, 2011). An illustration of this is the recent segmentation of plant pathology into several sub-specialisms, as can be observed in the profiles of plant pathologists who took part in this research.

Franklin, a plant pathologist who is further specialised in molecular plant-pathogen interactions, explained that developing work on the boundaries with molecular biology and other disciplines, along with the adoption of innovative techniques, has caused plant pathology to grow in complexity, producing the several levels of specialisation (Franklin, plant pathologist/molecular plant-pathogen interactions, 2011). A similar trend is observable in several areas of agricultural research.

Over time, mono-disciplinary efforts proved inadequate to cope with the depth of the problems that confront agricultural research in the context of globalisation. Ashleigh, a soil and plant nutrition scientist who has been at Embrapa for more than thirty years has been an eyewitness of this development. While in the past she used to have her own research targets, which she executed almost without interacting with other researchers, now she sees collaboration as compulsory:

> *Collaborating was not really necessary. In my case, for instance, I didn't involve other Research Units in my research. Occasionally, I would engage a fellow researcher from the Research Unit I worked at in a project. Nowadays, it is different: I need to collaborate with a colleague from some far away Research Unit, say in Amazonia, or an external organisation. It is a real challenge. (Ashleigh, soil and plant nutrition scientist, 2011)*

The idea that collaborative arrangements flourished in agricultural research in response to increasingly complex problems was emphasised by researchers from the three epistemic cultures (*in situ*, *in vitro*, and *in silico* research). Jacob (plant geneticist, 2011), for instance, who develops *in situ* research, stated that different specialisms need to be integrated so as "to produce more appropriate and robust solutions to complex problems". Matthew (plant geneticist, 2012 - validation stage), who develops *in vitro* research, confirmed this by saying:

> *Network research is a trend in science in general, because no one is able to dominate all issues involved in the solution of today's complex problems.*

Collaboration is also motivated by funding agencies, as a way to cope with the increasing sophistication of scientific instrumentation, the escalating costs of laboratory equipment and materials, and a growing number of scientists [48]. By encouraging collaboration, funding agencies guarantee wider access to the restricted budget available.

As a combination of knowledge and expertise from several disciplines and specialisms became necessary to tackle increasingly complex, real world problems, agricultural researchers became more mutually dependent and projects more multidisciplinary and complex. Corey (plant geneticist, 2011) explained how this develops in practice:

> *In order to satisfactorily respond to the current, complex problems, multi- and trans-disciplinary teams need to be formed. The message is straight-forward: people need to network. They need to collaborate. In the production of meat, for instance, it is not sufficient anymore to have the guy who understands and dominates the production system. To achieve the requirement of meat quality for exportation, biochemists, molecular geneticists, animal breeding specialists, food technologists, and many kinds of expert knowledge are needed.*

Ashleigh (soil and plant nutrition scientist, 2011), who is also a long-standing researcher at Embrapa, agreed that research teams now involve a larger number of collaborators and are more multidisciplinary than in the past. Franklin reinforced that current research projects "most commonly involve a team of experts, different disciplines and specialisms" (Franklin, plant pathologist/molecular plant-pathogen interactions, 2011).

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[48] As a result of an increasing popularisation of higher education, a greater number of scientists are being trained every year in Brazil. With more scientists at work in a wider range of institutions, a finite national budget for science is spread more thinly.

The multidisciplinary, collaborative arrangements in agricultural research are mostly temporary and situation-driven. Researchers collaborate to be successful when applying for funds or tackling a complex issue. After the project is finished, the collaborative configuration is dissolved. In a new opportunity, different coalitions will form, involving other groups of researchers.

Angelica (natural resources scientist, 2011) provided a concrete example of a multidisciplinary research effort, by relating the organisations involved in a cross-institutional collaborative project she coordinates and the different roles each partner plays:

> *My research involves a multidisciplinary team, with people representing several organisations. For example, Maua Institute of Technology is responsible for food development in my research; University of Sao Paulo carries out chemical characterisation studies; the Heart Institute (Incor) assesses biological effects of the products in humans; and University of Campinas develops the systems of cultivation and production in the State of São Paulo.*

Most researchers are optimistic about the increased multidisciplinarity in agricultural research. Different perspectives, methodological approaches and experiences bring heterogeneity to the process of agricultural knowledge production, "maximising the chances of providing feasible solutions to research problems", asserted Adele (soil and plant nutrition scientist, 2011). She gave an example from her own field:

> *We have more multidisciplinary projects now. I work side-by-side with soil and plant nutrition scientists, plant pathologists, geneticists, and many other disciplines' specialists and I believe this is a good thing. (Adele, soil and plant nutrition scientist, 2011)*

Some researchers remarked, however, that although multidisciplinarity is a common feature of current research teams, there is usually little articulation between the several specialisms. Each collaborator is in charge of a small part of the project and little effort is put into building a common analytical framework. In other words, rigid boundaries still exist between the disciplines represented in research teams. Every so often, multidisciplinarity is artificially constructed to meet the eligibility requirements of funding agencies:

> *Multidisciplinarity is almost the rule in research today. What I've noticed, though, is a deficiency in handling this multidisciplinarity; in taking the best advantage of the expertise available. Very often, I find that multidisciplinarity is only present to meet the requirement of funding agencies — people are listed as collaborators in a given research project but there is little interaction among them. Each one works on little bits of the research project, in their own disciplinary perspective. (Israel, soil and plant nutrition scientist, 2011)*

Researchers are sensitive, however, to the relevance of multi- and transdisciplinary collaboration for solving current challenges in agricultural research. "I believe we are witnessing the rise of a genuinely transdisciplinary research culture — it's inevitable", said Israel (soil and plant nutrition scientist, 2011).

In silico researchers acknowledge the emergence of the new Information and Communication Technologies (ICTs) as an important enabler of collaborative work (Merton, information systems scientist, 2011; Frederick, plant pathologist/ computational modelling, 2011). Real time, remote traffic of data and information has provided these researchers with an opportunity to develop experiments and work together in spite of physical or geographic barriers. Although not able to undertake experiments virtually, researchers from the other epistemic cultures have benefited from the new technologies to foster virtual exchanges and communication (Rosie, soil and plant nutrition scientist, 2012 - validation stage).

In effect, electronic communication is overtaking many of the more traditional forms of communication among researchers. Electronic mail, above all, has replaced personal letters and even telephone communication to a great extent, followed by Skype, virtual communities of practice, VOIP (Voice over internet) and other electronic tools that provide an immediate channel for information flow (Frederick, plant pathologist/computational modelling, 2011).

4.5.4 Internationalisation

While describing the research networks they are embedded within, researchers repeatedly mentioned the phenomenon of 'internationalisation' in agricultural research. Internationalisation is manifest in two ways. First, through an increasing demand, from countries located in the tropical and sub-tropical areas of the world, for

Embrapa's support in developing agricultural systems and building their agricultural research capacity. This is most commonly spoken of as the 'South-South collaboration' — in reference to the position of participant countries in the Southern Hemisphere. The participation of Brazilian researchers in this sort of collaboration is usually accomplished by means of knowledge sharing and transfer, most commonly involving *in situ* research (Christian, plant pathologist, 2011).

Many of the *in situ* researchers who were interviewed had already taken part in one or more international missions to support agricultural research and development in other countries. To support special knowledge transfer projects and technical collaborations, Embrapa has installed international Business Offices in Ghana, Mozambique, Mali, Senegal, Venezuela, and Panama. The issue is polemic, though, as some interviewees see the South-South collaboration projects as an overload for the Brazilian agricultural research system:

> *It puts a strain on our research capability and is disadvantageous from the perspective of national development. It is the kind of role that should not be assumed by the organisation. (Christian, plant pathologist, 2011)*

The second manifestation of the phenomenon of internationalisation is the growth of 'North-South collaboration' in research and the increasing demand for participation of agricultural researchers in international research endeavours, particularly involving *in silico* and *in vitro* research[49]. This differs from the previously described type of collaboration, not only because of the geographic location of participant countries, but because it involves research partnerships at the frontier of knowledge and joint development in science and technology, instead of knowledge transfer activities. Researchers illustrated North-South collaborations with the recent creation of Embrapa's Virtual Laboratories Abroad (Labex) in the USA, France, Netherlands, UK, and Republic of Korea. Alan (plant pathologist/molecular plant-pathogen interactions,

[49] A graphical representation of the current international scope of Embrapa, showing the Labex installations and the knowledge transfer projects was offered in the background to the case study (**Figure 14**, *Chapter Three*).

2011) was one of the researchers who had already participated in North-South research partnerships:

> *The main role of the virtual laboratories of Embrapa abroad is to get Brazilian researchers inserted in elite research groups and contribute to international research endeavours.*

Corey (plant geneticist, 2011) spoke about the wide range of international partners that Embrapa has, as a whole, and gave an example of the diversity of institutions that can be engaged in one multinational project:

> *Embrapa's got many formal and informal partnerships with national and international organisations, universities, and numerous multinational research projects. [...] In certain multinational projects, Embrapa has engaged with many different institutions to sort problems of common interest. For instance, one project that I know involved, at the same time, organisations such as the French Cirad (Centre de Coopération Internationale en Recherche Agronomique pour le Développement), the University of Florida, the Argentinean INRA (Institut National de la Recherche Agronomique), and the Brazilian Vale and Petrobras.*

Matthew, a researcher who took part in the validation of the data analysis, explained that the efforts of international collaboration started in the very beginning of Embrapa's activities, when Embrapa first hired undergraduates and sent them to be trained in renowned universities in the world. "Scientific partnerships evolved since then and are growing stronger", he said (Matthew, plant geneticist, 2012 - validation stage).

4.5.5 Engagement of farmers and other segments of society

Farmers are achieving more active participation in agricultural research. Not only are they consulted in the process of research agenda setting (section 4.4.2), but they are joining in the process of knowledge production, individually or as part of associations or cooperatives (Jacob, plant geneticist, 2011).

From a 'meso' perspective, however, the levels of participation of farmers in the knowledge production process vary across agricultural research cultures. Deeper engagement of farmers occurs in *in situ* research, at particular stages or throughout

the whole process. Christian (plant pathologist, 2011), who develops *in situ* research, commented on his engagement with farmers:

> *I am interested in integrated management of diseases and pests, an area which demands joint work with farmers. I enjoy working directly with them, calling into their properties, and hearing questions that can be answered through research.*

The engagement of farmers in *in situ* research was further alluded to by Megan (post-harvest physiologist, 2012 - validation stage), a researcher who took part in the validation of the data analysis:

> *The project I am coordinating at the moment involves consultancies with farmers and an analysis of the most common post-harvest problems.*

An example of the increasing engagement of the public in *in situ* research is named 'participatory research' — the growth of which was advocated by several researchers. Ashleigh (soil and plant nutrition scientist, 2011) highlighted the relevance of participatory research when working with small farmers:

> *Participatory research is growing in agricultural research. It is of special relevance when working with problems raised by small farmers.*

Jacob (plant geneticist, 2011) explained that through participatory research, traditional and academic knowledge are combined, which increases reflexivity in the process of knowledge production and accelerates the achievement of research results. He gave a practical example where participatory research has been important in his research area:

> *Participatory research has enabled a significant reduction in the time required for you to develop and recommend a new variety of a certain crop. If the researcher does not nurture a relationship with farms from the beginning of the research, he will end up with a product — such as a disease-resistant variety — that is not what the supply chain needs. With participatory research, this changes completely. (Jacob, plant geneticist, 2011)*

In the opinion of most researchers, participatory research reduces the waste of resources in developing a solution which is not practical or which is inappropriate in

the context of the farm and therefore cannot be adopted by farmers. Eric (natural resources scientist, 2011) noted:

> *People are taking research to the communities now. Research is being developed within the community. And it must be this way; otherwise we will produce wonders here that are useless in the field, either because farmers are not interested or because they don't have the necessary conditions to adopt the new technology.*

The closer contact between researchers and farmers, through participatory research, presents an opportunity to sustain transfer of knowledge and may provide insights to new research topics, as described by Israel (soil and plant nutrition scientist, 2011):

> *We work in direct contact with farmers. Sometimes they come here searching for a solution to a problem we already know and have the tools they need. But several times they happen to present questions that give birth to new research projects.*

Farmers participate significantly less in *in vitro* and *in silico* research, potentially due to the physical detachment of the experimental sites (the laboratory and the computer, respectively) and the technical knowledge involved, according to five *in vitro* and *in silico* researchers.

Madeline (genomics/proteomics scientist, 2011) explained that the impact of *in vitro* research is not immediate. The knowledge generated from *in vitro* research takes longer to be incorporated into the practice of agriculture, and for this reason, it does not attract the attention of groups of society as *in situ* research does:

> *In any kind of biotechnology study, research is done in the laboratory and the impact on society takes longer to appear. So, basically, I do not have much contact with the society or agents of the production chain while doing my research. The main relationship is with my own research peers. (Madeline, genomics/proteomics scientist, 2011)*

However, some *in vitro* research may include a later stage of validation of results in the field, when farmers are commonly involved. This was exemplified by Franklin (plant pathologist/molecular plant-pathogen interactions, 2011), whose work involves molecular studies:

> *The involvement of farmers is generally necessary in the later stages of the research project. For example: in the validation of alternative forms of disease control, in the evaluation of resistant cultivars, and so on. But as I said, this normally occurs in the final stages of the project.*

Interestingly, Frederick, a plant pathologist who is further specialised in computational modelling — meaning that most of his research is conducted *in silico* — reported to keep close contact with farmers. This is because his research usually included a validation stage in the field; so as to guarantee the availability of experimental fields, partnerships are established from the beginning of research:

> *We do not have experimental fields in the area of the Research Unit, so we need to build partnerships with farmers and conduct experiments in their grounds. So, they know from the beginning everything we are doing and communication with them is constant. (Frederick, plant pathologist/ computational modelling, 2011)*

Telephone, email and in-person conversations at Embrapa's Research Units or neighbouring farms were mentioned by researchers as the most common ways of communicating with farmers. Other more unidirectional forms of communication are talks in technology transfer events and training workshops, publishing articles in specialised magazines and all sorts of printed and electronic materials. Electronic tools, such as the internet and email, are of growing importance. For Christian (plant pathologist, 2011), all communication media are relevant, when it comes to spreading research results and communicating with farmers and non-specialist audiences:

> *The electronic medium is useful as a way of communicating with farmers. I think all ways of communication are important, because we need to reach different kinds of people. Flyers containing information of interest to local farmers, books, articles in magazines, or any other ways of communication are valuable.*

Most researchers emphasised, however, that farmers in general still prefer to talk over the phone or have a face-to-face conversation, except for urban vegetable farmers: these are the ones who make the most of electronic tools to communicate with researchers. From Israel's point of view, this happens because urban farmers are

usually better educated, information literate, and have access to the new technologies of communication and the internet (Israel, soil and plant nutrition scientist, 2011).

Communication between researchers and beneficiaries of research occurs not only on the initiative of each group, but the organisation, itself, encourages and demands from researchers that a close contact be kept between them and the final users of their research outputs. Exception is only made to situations where the potential of generating a patent is high, as in the case of some of Alan's (plant pathologist/ molecular plant-pathogen interactions, 2011) and Michael's (plant pathologist/ biological control, 2011) projects.

Agricultural researchers also engage in research dissemination activities — those directed towards other sectors of society and not only farmers and agents of production chains. In this regard, Angelica (natural resources scientist, 2011) argued that the communication between researchers and society as a whole has intensified over the last decades, using as an example the polemics around Genetically Modified Organisms (GMOs):

> *I think society is more attentive now to what is being done in agricultural science, particularly after the emergence of the Genetically Modified Organisms. The debate captured a wide audience and I think this was when society woke up to the fact that it needed to have a voice in agricultural science; really watch over what is being done. Despite the total misconception that many people have about GMOs — which sometimes disturbs and gets in the way of our work — the enhanced dialogue between scientists and society is undeniably healthy.*

Angelica went on to say that researchers are encouraged by the organisation's headquarters to communicate with the several sectors of society. This is most commonly done via the institutional radio and TV programs, and the many other communication vehicles Embrapa uses:

> *Managers at Embrapa Cerrados frequently arrange for our participation on Embrapa's radio and TV programs. It is an institutional practice: we are required to inform our journalists when we achieve a result that can be communicated to the public, so they can arrange the ways for the best dissemination of that information. With their support, my research has been*

> *disseminated in several external communication channels — television, newspapers, magazines... (Angelica, natural resources scientist, 2011)*

The demand for information from society is so high that Customer Services have recently been established in each Research Unit, to respond to the first contact of farmers and the general public. Researchers are only involved when strictly necessary. Adele (soil and plant nutrition scientist, 2011) indicated the Customer Service at the Research Unit where she works as an example of good practice:

> *Our Customer Service is in high demand and is working well. It is being promoted as a model now, for other Research Units which are interested in setting up their services. They have a database with the most common questions, so they don't need to contact the researcher all the time; only when something new is being asked. [...] Another important thing is that we are keeping records of anyone who establishes a contact with the Unit through the Customer Service. Now we know who the person is, even before serving him or her.*

Researchers who develop *in situ* research participate in research dissemination activities to a greater extent than those in *in silico* and *in vitro* research. Christian (plant pathologist, 2011), for instance, mentioned producing more of what he calls 'non-scientific communications' than scientific papers:

> *It gives me more pleasure to work on non-scientific communications addressed to farmers or the general public than publishing a paper. I've been publishing a lot in specialised magazines and the focus of these articles is on practical aspects of the control of plant diseases, information about pathogens, and so forth.*

Rosie, who develops *in situ* research and participated in the validation of the data analysis, emphasised the increasing interest of society as a whole in agricultural research, and commented on the engagement of farmers in the research projects she develops: "People are more and more interested in research; I work with farmers very often, so as to validate potential technologies" (Rosie, soil and plant nutrition scientist, 2012 - validation stage).

4.6. Information infrastructure and resources as inputs to agricultural research

Researchers deal with 'information-as-thing' (Buckland, 1991) on a daily basis — particularly (but not exclusively) scientific literature, research data and grey literature. While analysing information as input to agricultural research, however, the notion of 'information-as-knowledge' (Buckland, 1991) emerged as equally important.

The following subsections examine agricultural researchers' needs, practices and attitudes towards 'information-as-thing' (sections 4.6.1 to 4.6.4) and '-as-knowledge' (section 4.6.5) (Buckland, 1991). The last section (4.6.6) focuses on the current roles, responsibilities and practices towards information and knowledge management at Embrapa.

4.6.1 Accessing scientific information in the digital paradigm

Seeking and retrieving 'scientific information' is a preliminary step in many scientific activities; e.g. writing a research proposal, a report or a journal paper, designing experiments, or selecting a research methodology. Researchers also search for scientific information[50] as a way of keeping up-to-date with research in their fields.

Libraries located at each of Embrapa's Research Units have traditionally played an important role in supporting research through selecting, purchasing, preserving collections, and providing access to scientific information. Over the years, budgets and physical space limitations, combined with increasing costs of print journal subscriptions, caused Embrapa's libraries to change focus from local collections toward shared collections across Research Units. This was made possible through the consolidation of the organisation's Library System, as explained by Vanessa (information manager, 2011).

[50] The term 'scientific information' is used here in reference to that contained in scientific (scholarly, academic) publications in peer-reviewed journals and conferences proceedings, as well as scientific books. Scientific information is, therefore, a form of 'information-as-thing' (Buckland, 1991).

Keeping up with technological advances, a shift from the print to the digital mode occurred recently in Embrapa's scientific information services. Essentially, the organisation embraced a governmental initiative to federate relevant national and international scientific journals in all areas of knowledge, into a single digital library, providing unified access to Brazilian universities and participating research organisations — the Portal of Scientific Journals[51].

Apart from some criticism concerning the interface of the Portal, the absence of a few relevant journals in areas of interest[52], and difficulties with accessing older scientific papers, the majority of researchers commented on their satisfaction with the platform and the scientific information services at Embrapa. Besides Portal Capes, researchers have used a wide range of online, scientific bibliographic databases on a daily basis, to keep in touch with the scientific literature in their fields. The most cited were Science Direct (http://www.sciencedirect.com/), CAB Direct (http://www.cabdirect.org), PubMed (http://www.ncbi.nlm.nih.gov/pubmed/), Web of Knowledge (http://apps. webofknowledge.com/), and Google Scholar (http://scholar.google.com.br/).

The fact that the library collections are now primarily digital and accessible online has allowed users to reach the literature without physically visiting the library and this has confused some of them about who is behind the services they use — "they do not realise that the information they access digitally is made available for them by the Library System" (Vanessa, information manager, 2011). Having already switched into

[51] The Portal Capes, as it is commonly known in Brazil (http://www.periodicos.capes.gov.br/), was created in 2000 by the Federal Agency of Support and Evaluation of Postgraduate Education (Capes), which is part of the Brazilian Ministry of Education. Nowadays, Portal Capes provides full text access to more than 30,000 scientific journal titles. The access is free of charge to universities and research institutions which have an educational component — that is, those that run a recognised postgraduate course, thus contributing to Capes' personnel formation programs. Any other research institution wishing to get access to the Portal Capes needs to purchase access through expensive, annual contracts. This is the case for Embrapa, as it does not have a role in personnel education.

[52] One of the reasons for this is that many journals of interest in agricultural research are not indexed with Science Citation Index (SCI) or other important bibliographic databases. To provide an example, from the five scientific journals published by Embrapa, only one — the Brazilian Journal of Agricultural Research (https://seer.sct.embrapa.br/index.php/pab/index) — is indexed in relevant international databases (ISI - Web of Knowledge, CAB Abstracts, Agris, and Scielo).

digital mode, agricultural researchers see themselves as literate[53], independent information seekers.

4.6.2 Accessing unpublished, research-related information: the value of internal communication flows

Getting to know what is being done elsewhere inside and outside the organisation is as important in agricultural research as getting to know what has been achieved in the past, via the formal scientific communication system. Most of the agricultural researchers' needs concerning unpublished, research-related information[54] are related to ongoing research projects. Equally important sources of information are reports of completed projects, research proposals and grey literature in general, which usually contains pieces of original research data but which are outside the realm of commercial publishers and poorly controlled by catalogues, databases, and bibliographies.

This relates to the fact that, in a context of rapid advancement of science, awaiting publication of results in scientific journals in order to become informed could signify a waste of time. At the time of data gathering, however, there was no institutional service to support access to information from completed or ongoing projects: "Sometimes we need information about completed and ongoing research projects and it is not available" (Christian, plant pathologist, 2011).

In Angelica's opinion, the fact that researchers do not know the organisation's research portfolio is prejudicial: "Because of this, there is a lot of reinventing the wheel at Embrapa", she said (Angelica, natural resources scientist, 2011). Frederick (plant pathologist/computational modelling, 2011) corroborated this by saying:

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[53] 'Information literacy' is "the ability to make efficient and effective use of information sources", according to Julien (2001, p.1054).
[54] Information and data from ongoing and completed research projects are types of 'information-as-thing' (Buckland, 1991).

> *Sometimes you have an idea, but you don't know whether it has been tried before or even whether this idea is already being developed somewhere else inside the organisation. It can be a complete waste of resources and time if you don't have access to this sort of information.*

Adele (soil and plant nutrition scientist, 2011) offered a practical example of a situation where ignorance of the organisation's research portfolio resulted in waste of time and frustration:

> *I was writing a research proposal and I just had no idea that there was another project already being conducted to which my proposal could be aggregated. I only learned about that later on, when talking to some people and one of them advised me of the concurrent research project.*

The situation is more critical when projects are financed by an external agency. In such a case, project leaders have much autonomy and there is little concern with disseminating what projects are about, their developments and achievements, as noted by Franklin (plant pathologist/molecular plant-pathogen interactions, 2011):

> *Information about ongoing or completed research projects is not easily available to researchers. This would be an improvement. But the difficulty, I think, is that many of the research projects are financed by external agencies, and thus not much monitored by Embrapa.*

In Alan's opinion, information about ongoing research projects should be accessible to all researchers at the organisation, to allow them to identify opportunities in their own disciplines (Alan, plant pathologist/molecular plant-pathogen interactions, 2011). He went on to say that organising this kind of information and making it available for researchers is a requirement for a research organisation to succeed and produce innovation:

> *As a researcher at Embrapa, I don't know what my fellow researchers are doing in a different Research Unit. To avoid duplicity, it is very important to have this information. […] Our role as a public research organisation is to do research and generate technological solutions for the agriculture sector. To succeed in that, this company needs to organise this kind of information and foster network research. (Alan, plant pathologist/molecular plant-pathogen interactions, 2011)*

Christian (plant pathologist, 2011) argued that lack of awareness of the organisation's research portfolio is a barrier to the processes of knowledge sharing and creation. Vanessa (information manager, 2011) acknowledged the problem and indicated that initiatives were already in place to address this problem and to provide researchers with access to essential information about research projects, particularly initial proposals and final reports.

As a consequence of the scenario depicted above, informal communication became an important tool to disseminate unpublished research-related information (or information which is not intended to be published in the traditional scientific communication system): "The way we get information of interest is basically through our informal network, if not available yet as a scientific publication", said Alicia (plant pathologist/molecular mechanisms of tolerance to stress, 2011). Maryann (soil microbiologist, 2011) also noted that it is mainly through informal conversations and participation in conferences that she gets to know what is being done at Embrapa:

> *We get more information through conversations and participation in conferences. Honestly, I access the work done at Embrapa in the same way as I access information about research that is developed in external organisations: via literature reviews, scientific publications, and participation in conferences. There is no easy access to this information because we all work at the same company.*

Lindsay (molecular biologist, 2011) explained that agricultural researchers rely heavily on their colleagues for information, choosing their research topics and methodologies, broadening their thinking and furthering their research. When this becomes difficult, she said, 'internal communication' is often to blame. In fact, most researchers noted communication difficulties between individuals (in the same department or across departments), from superiors to subordinates and vice versa. Alan (plant pathologist/molecular plant-pathogen interactions, 2011) indicated the connection between Embrapa's central departments as a root to the problem of poor internal communication:

> *Communication between the different poles, different units at Embrapa, is poor. In my case it is even more traumatic because, to develop my job well, I need to know what is happening at Embrapa in several areas across the country. But this information is not available, basically due to a problem of*

> *connection and internal communication between Embrapa's central divisions. There is no fluid communication inside the same building — between the Department of International Relations and the Department of Research and Development, for example. It is a real problem.*

Alicia (plant pathologist/molecular mechanisms of tolerance to stress, 2011) also commented on the problems of communication within and among Research Units, concluding that they constitute a barrier to collaboration.

4.6.3 Information needs of a non-scientific nature

Most of the time, agricultural researchers' information needs are of a scientific nature — the literature or unpublished research-related information and data. But to accomplish their research and succeed in a range of activities, they commonly search for information ('-as-thing') which is not directly related to research.

Searching information about potential research partners is a recurrent practice of researchers — bearing in mind that Embrapa is a large organisation, with numerous geographically dispersed Units and almost ten thousand employees. However, information about the internal expertise or 'who knows what and where' at the organisation is not easily accessible, making it difficult for researchers to build professional partnerships:

> *Finding out who knows what at Embrapa is a struggle. It is hard to find out about the internal expertise here... It is not always a smooth and dynamic process. (Alan, plant pathologist/molecular plant-pathogen interactions, 2011)*

Most of Adele's (soil and plant nutrition scientist, 2011) research partners are from the local university or the same Research Unit she works at — which is remotely located in the countryside of the Bahia State. In her opinion, the difficult access to information about potential research partners is contradictory to the notion of multi-user laboratories, which is being encouraged by the organisation's headquarters:

> *We are talking a lot of multi-user laboratories, and of creating a common structure that everyone inside the organisation may use, but we could improve the way we make information available. Who are we going to work*

> *with? What is being done elsewhere? I see this as an opportunity for improvement at Embrapa. (Adele, soil and plant nutrition scientist, 2011)*

Just like with information about ongoing research (as already discussed in section 4.6.2), informal networks operate as a social source of information about human resources, Tiffany (plant geneticist, 2011) explained. Franklin (plant pathologist/molecular plant-pathogen interactions, 2011) and Margaret (molecular biologist, 2011) confirmed that it is only through personal conversations with more experienced researchers that they get information about who knows what at the organisation — and where this person is located.

Such is the relevance of knowing about potential research partners in the same organisation (especially when it possesses almost ten thousand employees), that a small group of researchers have organised a skills database in their research area — that of natural resources (Angelica, natural resources scientist, 2011). Alternatively, others resort to Google or to external information services to find out about Embrapa's human resources, as reported by Margaret (molecular biologist, 2011):

> *There is no institutional service that facilitates access to information about the human competencies available at Embrapa. Maybe one could use information services provided by Cnpq (National Council for Scientific and Technological Development) to get this information.*

Thomas (information manager, 2011) associated the difficulties with identifying potential research partners inside the organisation with the absence of an institutional 'skills database' (or 'talent bank') where employees can find colleagues with specific competencies. In this regard, the information managers who took part in this research believe that the creation and maintenance of a corporate skills database is the responsibility of the Department of Human Resources rather than of the divisions in which they work (Thomas and Vanessa, information managers, 2011).

Researchers also commented on the need to access certain non-bibliographic, non-research-related information. Issues such as geography and general statistics (political and social aspects), patents and intellectual property (economic aspects), and law and biosafety (legal aspects) are the most common complementary information needs of agricultural researchers. Colton (molecular biologist, 2011), for instance, mentioned information from patents as a necessary input to his work:

> *My research interests are very particular. I am sure no one else inside the organisation is doing anything similar, but what I really need is information from patent databases. I found this training opportunity in São Paulo and I got trained in patent databases searching. I use this sort of database more than the traditional, scientific bibliographic ones.*

The quote above illustrates how much *in vitro* researchers are concerned with intellectual property issues and regulations. Their information needs, therefore, reflect the current complexities and trends in the agricultural research system. The following comment, by Margaret (molecular biologist, 2011), is illustrative of the complexities involved in *in vitro* research:

> *My research can potentially generate a patent. The problem is that, as soon as I identify and isolate a gene of interest, I begin struggling to access information in patents' databases. I need to know who is working with that subject worldwide. Will I infringe anyone's right if I pursue a patent with this methodology? I had to learn how to find this kind of information by myself and it was not easy! I found no support in the information services provided by the organisation. […] I would like to have some support with legal information and advice, so as to not infringe on any law while doing my research, which is becoming more demanding and complex with time.*

Since providing for the variety of information required by current research is beyond the current service provision at Embrapa, researchers are learning by themselves how and where to get the information (-as-thing) they need.

4.6.4 Research data as input to research

Research data[55] is an important resource for agricultural researchers, particularly those developing *in vitro* research. Accessing scientific data deposited in online

[55] For the purpose of this study, 'research data' is defined as the facts which result from scientific observation. Being a type of 'information-as-thing' (Buckland, 1991), data can be recorded in lab-books, field-books, electronic databases, and so on.

databanks such as NCBI (National Center for Biotechnology Information), for instance, is a common requirement in biotechnological techniques or those dealing with genomic-related information, as noted by Luke (genomics/proteomics scientist, 2011). Eric (natural resources scientist, 2011), who is also an *in vitro* researcher, mentioned routinely accessing data in external germplasm banks. Interestingly, accessing research data which is generated internally in the organisation is far more challenging.

Employment contracts with Embrapa establish that field-books, lab-books and data of any form resulting from research activities at the organisation, belong to the organisation. However, there are no official guidelines as to how this should be done and no pattern can be observed across Research Units, regarding research data management. The majority of the researchers admitted to recording raw data in a lab- or field-book, with the remainder using their personal computer to record and store research data. Only five researchers reported the use of a specific research database to enter raw data from their experiments, in addition to maintaining lab- or field-books.

At the time of this research, initiatives of lab-book digitisation were ongoing at some Research Units. Eric (natural resources scientist, 2011) underlined that this was "not as a uniform development across Research Units", though. With few exceptions — such as in specialist areas where data needs to be treated digitally in appropriate databases in order to be analysed — there is "little effort to organise research data and make it available for use by others" (Christian, plant pathologist, 2011).

Remarkably, research data is well-organised and managed in laboratories certified by the International Organization for Standardization (ISO) (Franklin, plant pathologist/molecular plant-pathogen interactions, 2011). This happens because, in order to achieve certification of Good Laboratory Practices (GLP) and obtain approval to run certain types of analyses, laboratories need to employ several data management procedures. Michael (plant pathologist/biological control, 2011) explained:

> *Several laboratories in our Research Unit have already qualified with GLP and other quality control certifications. Besides other requirements, all activities developed in the laboratory need to be recorded in lab-books, following recommendations of the certifying entity.*

Sharing research data is not part of the culture at Embrapa, however. Usually, research data is only exchanged between research partners working on the same project (Alan, plant pathologist/molecular plant-pathogen interactions, 2011; Margaret, molecular biologist, 2011). Israel (soil and plant nutrition scientist, 2011) acknowledged the issue:

> *Every researcher knows that everything they develop is owned by the organisation, but in practice everyone acts as if research data were each researcher's private property.*

Particularly in *in vitro* and *in silico* research, there is reluctance to disclose and share raw data, which contrasts with their greater need of access to research data in online databanks, as mentioned before. When questioned about this, researchers expressed concerns with intellectual property rights and fear of plagiarism, as Merton (information systems scientist, 2011) explained:

> *We want to share data, but the problem is: how are data going to be managed? How is the process going to be regulated and controlled? Many researchers are concerned with original data being used by others without their consent or in an inaccurate way.*

Merton (information systems scientist, 2011) noted, however, that research managers were already sensitive to the need for research data to be organised and accessible. But in his opinion, any attempt to solve this issue is hampered by the high costs involved in the development and maintenance of a robust information system. Also, he thinks that people are so overloaded with work that they are not interested in changing the ways they manage their own data — in their lab-books, field-books or personal databases. From a different standpoint, Thomas (information manager, 2011) argued that not sharing research-related data and information is a problem that has cultural roots:

> *The problem is how to make researchers provide information about their research and share with others. This is not going to be solved through the institution of a new organisational process: a change of culture is essential, so that people are more open to share information. Of course there are things that have to be protected, where intellectual property issues are*

implicated, but in general, I think people don't share information because information is power.

Robert (knowledge manager, 2011) shared a similar opinion and said that non-collaborative behaviour is so attached to the organisational culture that "many researchers don't even admit that the data generated in their research can be useful to someone else". Madeline (genomics/proteomics scientist, 2011) was one of the researchers to question the usefulness of sharing research data: in her view, "data which is relevant is published in scientific papers or conferences' proceedings".

4.6.5 Difficulties with the sharing and retaining of 'information-as-knowledge'

This issue of tacit knowledge retention following researchers' retirement emerged as a central theme in the interviews. A large group of researchers had just left the organisation in a retirement incentive program and, "due to an ineffective knowledge management strategy, tacit knowledge and research data were being lost", Adele (soil and plant nutrition scientist, 2011) argued.

Christian (plant pathologist, 2011) asserted that the amount of tacit knowledge that the organisation had lost in the previous years was inestimable. In his opinion, however, the roots of the problem of tacit knowledge retention at Embrapa are in the managerial process of personnel hiring and retirement:

> *I think the organisation already understands the importance of retaining knowledge when an employee is retiring. But the problem is that the hiring process does not allow time for the process of knowledge transfer. First someone is retired and just months later a substitute is hired. [...] The amount of knowledge that is lost in this process is ridiculous. Tacit knowledge is not written anywhere! (Christian, plant pathologist, 2011)*

Adele (soil and plant nutrition scientist, 2011) argued, however, that even if the hiring/retirement processes were ideally aligned and a formal policy on knowledge transfer was created, many researchers would still leave the organisation without sharing research data or knowledge with their substitutes due to non-collaborative behaviour:

> *Some people are not worried about transferring knowledge to their substitute before leaving the organisation. We've been trying to solve this, but with some people it is really hard. They feel as they possess all this material, all this knowledge is theirs and does not pertain to the organisation.*

Robert (knowledge manager, 2011) stated that the general culture of research is a non-collaborative one. In his opinion, such culture influences the information practices and the behaviour of researchers towards knowledge sharing:

> *The culture at Embrapa is one of 'non-sharing'. Generally, these researchers come from international academies and they like to work in isolation, as in your PhD course, for example. You run* your *experiments, collect* your *data, write* your *thesis, and when you arrive here at Embrapa, you have* your *lab,* your *workbench,* your *'microorganism',* your *data... It is not a collaborative culture. (Robert, knowledge manager, 2011)*

Researchers that work with *in vitro* and *in silico* research, particularly, are reluctant to share what they know, for being afraid of plagiarism and losing priority in scientific discovery, as mentioned in the previous section. To more efficiently manage information and knowledge at Embrapa, a cultural change would be necessary:

> *This is the most important objective with knowledge management at Embrapa: to convert this individualistic culture of research into a culture of knowledge sharing. It is a difficult endeavour and it is going to take time and dedication. (Robert, knowledge manager, 2011)*

The loss of tacit knowledge and the poor management of research data are associated issues, Adele (soil and plant nutrition scientist, 2011) argued. She gave a factual example where someone retired and took away lab-books and all research data records:

> *We were looking for certain data everywhere and couldn't find it; it was when a colleague of ours said: 'oh, I think that person, who retired recently, has all these data'. Then we went to visit him at his house and found he had retained many materials that should have been kept at Embrapa, including all his lab-books. We were lucky that he hadn't thrown them away. (Adele, soil and plant nutrition scientist, 2011)*

For Adele, this is not an isolated example. The same situation happened in many cases, with the recent group retirement incentive.

4.6.6 Roles, conceptions and misgoverning of information

Several divisions of Embrapa are concerned with aspects of information and knowledge management (IKM). Each of them takes initiatives and coordinates a range of activities which impact the whole corporation.

The Department of Research and Development (DPD, in Portuguese), for instance, coordinates the management of information in support of managerial decisions and also, the management of information related to R&D (Thomas, information manager, 2011). The Secretariat for Management and Strategy (SGS, in Portuguese) coordinates the corporate strategy of knowledge management (Robert, knowledge manager, 2011). The Department of Technology Transfer (DTT, in Portuguese) manages information systems in support of the process of technology transfer. Embrapa Technological Information (which is not a central division of Embrapa but a decentralised Service Unit) is responsible for the management, organisation and dissemination of information for societal audiences. Finally, another two divisions are responsible for developing general information systems (Vanessa, information manager, 2011).

The fragmentation of roles and responsibilities across various divisions, combined with the high levels of autonomy in decision-making about information for the common good of the organisation is detrimental, however, as it leads to overlapping of activities, duplication of efforts, and uncoordinated operation. Moreover, because there are no formal guidelines or policies regarding IKM at the organisation, these activities are not conceptually or strategically congruent.

Due to the lethargy and lack of centralised control, Vanessa (information manager, 2011) said, “many Research Units develop ‘home-made’ solutions to deal with IKM”. In her opinion, some of these solutions have grown into interesting practices which should be further evaluated and disseminated to other Units, but “there is little effort in this direction; there are no guidelines or policies regarding this” (Vanessa, information manager, 2011).

The relevance of developing an institutional policy for IKM was emphasised by the three information and knowledge managers that took part in this study. Vanessa (information manager, 2011) highlighted that even the Library System, composed of 42 libraries distributed in the several Units of Embrapa, exists just in practice — there is no formal document instituting or ensuring legality to the Library System at Embrapa. Besides, the system is not coordinated by a central division, which she sees as a compromise:

> *A decentralised unit does not enjoy legitimacy to rule over Research Units and dictate the organisational information strategy. Just as important, they do not have the necessary funds or the structure to accomplish the job. (Vanessa, information manager, 2011)*

Thomas (information manager, 2011) said that the very nature of Embrapa — being a research organisation — and its structure, which is segmented in several research and administrative divisions distributed over the Brazilian territory, brings complexity to the strategic management of knowledge. He described the most recent attempt to create an appropriate structure and consolidate an organisational strategy towards knowledge management at Embrapa, with the launching of an institutional knowledge management project. The project had the support of Embrapa's board of directors and produced a conceptual model for knowledge management at the organisation. The project adopted a dialogic and participative methodology, involving representatives of several divisions of Embrapa. One year after its completion and delivery of the final products, however, nothing really changed (Thomas, information manager, 2011). In Robert's opinion, this was because "the subject is too abstract, too complex, so everything was shelved [...] People find it difficult to comprehend the issue, because it deals with the intangible" (Robert, knowledge manager, 2011). Vanessa (information manager, 2011) also contended that many important issues were being overlooked due to a lack of understanding of the area. In her own words:

> *Many managers do not have a strategic view of the area. Then, it is a struggle to convince them of the importance of stuff. It is really complicated. They have difficulties dealing with abstract things, and information is somewhat abstract. (Vanessa, information manager, 2011)*

The exaggerated focus of the organisation on information technology, when problems are in fact related to the management of information and knowledge, was also highlighted by interviewees. In this regard, Vanessa (information manager, 2011) said:

> *They think information technology is more strategic than information and knowledge management. We now have an organisational policy of information technology and they are giving much emphasis to technological issues. In my opinion, technology is just a tool.*

The interviewees expressed concerns with the increased emphasis of the organisation on serving the society and the external public, in terms of their needs of information and knowledge. Information systems and services directed towards the external public have evolved into robust and efficient resources, while those in support of research have shrunk:

> *It seems that nowadays people are much more concerned with external audiences and the dissemination of information to these audiences. They are looking after external audiences, which I think is important, but the internal audience, that is, the team of researchers, is not as well assisted. Dissemination of information to non-specialist audiences is one thing; information in support of research is a completely different thing. We cannot forget internal users, when providing information services. (Vanessa, information manager, 2011)*

A major change with the libraries exemplifies this transition. With libraries being used less by researchers, these spaces are being strategically redirected to external users. For Vanessa (information manager, 2011), this is a mistake, as "the main objective of Embrapa's Library System has traditionally been to support R&D, which is the flagship of this company". She pondered, however, that despite using information and knowledge on a daily basis, researchers are not completely aware of how improved governance can contribute to the success of the activities they develop, and of the organisation as a whole.

Robert (knowledge manager, 2011) underlined the fact that 'knowledge', 'information' and 'innovation' are managed separately at Embrapa, with overlapping initiatives being developed across several instances. Under such circumstances, "the central power of the organisation to decide about information and knowledge management is

impoverished", he said. From Robert's perspective, knowledge, information, data, and innovation are concepts to be treated in an integrative way, under the umbrella of an IKM strategy. Vanessa (information manager, 2011) supported his view:

> *I understand someone should have an integrated look at the question of information, data, and knowledge management. The fragmentation of initiatives spread over several departments is prejudicial to the overall strategy in the organisation.*

Thomas (information manager, 2011) emphasised that, conceptually, IKM is not well-discussed and explored at Embrapa; therefore, a theoretical framework needs to be developed first, considering the organisational culture and the reality of doing research at Embrapa. Robert (knowledge manager, 2011) argued, however, that the problem of conceptual confluence is less relevant to IKM at Embrapa than a cultural problem. The fact that the knowledge management model had not been implemented yet, for instance, would be "indicative of a problem with cultural roots, which is the very competitive culture at Embrapa" (Robert, knowledge manager, 2011).

Although external competitiveness might be a driving force in research, high levels of internal competitiveness impose difficulties for an information strategy and contribute to a non-collaborative information culture at the organisation:

> *External competitiveness — we know that it exists and this is acceptable. Now, internally, it makes no sense. In the ideal world, Embrapa would demonstrate collaboration internally and competition externally. But what happens now is that the company competes outside and within itself at the same time. This inhibits collaboration, and the process of information and knowledge sharing. (Robert, knowledge manager, 2011)*

The information and knowledge managers advocated that structural changes need to take place, so that IKM can be effective at Embrapa: there needs to be a team and a structure with a legitimate mandate for knowledge and information management, with "unreserved support from the directory board, given that a change of culture is not an easy task to accomplish" (Robert, knowledge manager, 2011). Vanessa (information manager, 2011) shared the same view:

> *IKM is an issue of such importance that it should be subject directly to the directorship. This is not what happens at Embrapa: several decentralised*

> *departments have a role in this issue and the organisation lacks central power when it comes to managing information and knowledge. Besides, central governance would be important to give prominence to all the processes. It needs to be agile, because information is so dynamic! Things change quickly nowadays...*

Conversations undertaken in the validation of findings confirmed the main issues reported in this section, in relation to the management of information and knowledge at the organisation.

4.7. Scientific outputs of agricultural research

This section analyses the dissemination of agricultural research outputs, the existing mechanisms of quality control of the scientific production at Embrapa, and how this production is assessed and rewarded. Different practices of scientific communication, which were found across the epistemic cultures of agricultural research, are explained.

4.7.1 Scientific communication practices

Research results are commonly disseminated and made available to the scientific community through publication in established communication channels. The two main channels for communicating results of *in vitro* and *in silico* research are peer-reviewed scientific journals and conferences, as Tiffany (plant geneticist, 2011) summarised:

> *No other channel has so much penetration into the scientific community than the scientific journal. Second place is participation in conferences, seminars, and the like.*

Between the two channels, however, *in vitro* and *in silico* research give preference to scientific articles, as can be noted in the quote below:

> *Basically, the people who are interested in my research are from the scientific community, so communication is basically limited to them. (Alan, plant pathologist/molecular plant-pathogen interactions, 2011)*

In *in situ* research, however, communication is more extensive between researchers and farmers, rural extension professionals, and agents of supply chains. In this case, participation in conferences overpowers the scientific journal as the main channel for

communication of results, with informal talks in events and technical communications directed to farmers and rural assistants playing an important role in the diffusion of research results (Ashleigh, soil and plant nutrition scientist, 2011). This is because the impact of *in situ* research is mostly local and temporal, and results are sometimes of little interest for other audiences, even inside the scientific world. Israel (soil and plant nutrition scientist, 2011) clarified this by saying that most results of plant science and general agriculture research are not usually published by scientific journals. Instead, these are communicated in technical notes to farmers. Jacob (plant geneticist, 2011) explained the different types of outputs produced by agricultural research as a whole:

> *At the same time agricultural research may potentially operate in the frontier of knowledge, it also produces results of interest to a more restricted public; basic information and instruction to farmers and agricultural technical assistants.*

The difference was further alluded to by Ashleigh (soil and plant nutrition scientist, 2011):

> *Researchers in fields such as Biotechnology publish more than those in other areas. Besides papers, they also publish books. Because my research usually results in the recommendation of a new agricultural practice, what I do publish a lot is technical notes to farmers and rural technical assistants, such as fertilisation recommendations for banana, passion fruit, mango, and other fruit crops.*

Regarding the patterns in scientific papers, it was observed that authorship conventions and number of authors per paper varies not only across but also within the different epistemic cultures, in a way that makes it difficult to identify any generalised practice. For instance, in communication of *in situ* research, the leading researcher can be the first (as in soil microbiology, plant pathology, and natural resources research) or the second (soil science) author. In most communications of *in vitro* research, however, the senior researcher is the last in the author list, with the remainder defined by the actual participation in the research. An artificial arrangement, however, whereby all participants in the research get a chance of being last author, with the position of names in authors' lists alternating randomly is becoming increasingly common in *in vitro* research (Angelica, natural resources scientist, 2011; Tiffany, plant geneticist, 2011).

Regarding the decision about 'where' to publish, researchers from the three epistemic cultures have similar views. As a whole, they consider the scope of the journal and the impact factor as the most important criteria. The following comment by Alan (plant pathologist/molecular plant-pathogen interactions, 2011) is illustrative of this fact:

> *The determinant factors when deciding where to publish are: first, the area and scope of the scientific journal and second, the impact it has.*

Madeline (genomics/proteomics scientist, 2011) emphasised the impact factor as the most relevant indicator, when choosing a national or international journal:

> *Basically, the impact factor is the most important criteria when selecting a scientific journal to submit a paper, either nationally or internationally.*

Speed of the review and publication process (turnaround time), followed by electronic availability also emerged as relevant factors when choosing a scientific journal. In fact, the preferred journals by agricultural researchers were found to adopt a hybrid model, in a sense that they are still published in both, print and electronically on the internet, with an increasing interest on Open Access publications:

> *Usually these journals have a dual model — the electronic and the printed version. But nowadays we do not use paper anymore: everything is in .pdf format and you can download to your computer. I also give preference to journals that are not paid for access. I prefer Open Access journals because they are distributed more easily and quickly. When you publish, the goal is to reach the audience with information. (Angelica, natural resources scientist, 2011)*

Alan (plant pathologist/molecular plant-pathogen interactions, 2011) also commented on the important role of Open Access journals to the wide dissemination of information:

> *Basically, we publish in electronic journals, with Open Access journals gaining importance over the years.*

Whenever the knowledge produced is relevant for the international scientific community, preference is given for publishing in English, as stated by most researchers. Frederick (plant pathologist/computational modelling, 2011), for instance, noted:

> *Researchers tend to prioritise international journals with a relevant impact factor and which are obviously published in English. The second choice would be Brazilian journals with a good impact factor and where the paper can be published in English. Just in last place is any national journal published in Portuguese.*

The choice for publishing internationally is justified by the commonly held perception amongst researchers that papers are read more and cited more if they are written in English, Christian (plant pathologist, 2011) explained. Michael (plant pathologist/biological control, 2011) gave a definitive account of the situation:

> *It is easily noticeable that Brazilian researchers in my field who aren't fluent in English — and thus are only able to publish in national journals — have no visibility at all. Although they have loads of papers published, they have no impact in the scientific community.*

The turnaround time also motivates researchers to publish in international journals, since most of them believe that publishing abroad is quicker than in a Brazilian journal:

> *The publishing process of some Brazilian journals takes so long that it is not worth it. I prefer journals that are quick in the analysis process and in their responses and that are not excessively demanding. (Angelica, natural resources scientist, 2011)*

The fact that funding agencies give special value to scientific production in English also influences the decision of researchers of where to submit a paper, according to Adele (soil and plant nutrition scientist, 2011). Because of this, added to the increasing pressure to publish as many papers as quickly as possible, international journals are usually preferred:

> *In some cases, it takes more than a year to get a position regarding paper acceptance or not. The gap between research and results dissemination needs to be shortened nowadays. That is when publishing abroad is beneficial; it is quicker. (Christian, plant pathologist, 2011)*

In the opinion of Lindsay (molecular biologist, 2011), however, it is not necessary to opt for an international journal, to have a paper published in English. Some Brazilian

journals publish in English and others include a translation to this language, besides the original paper in Portuguese.

Although there are many advantages to publishing in English, the issue of communicating results in a foreign language is controversial for *in situ* researchers, given that the majority of the results have a local impact and are directed towards local audiences:

> *Much of the information generated in my research is just of local interest. The demand is local and the impact is right here. Actually, my research results fall more within the range of knowledge transfer publications; directed to farmers. (Ashleigh, soil and plant nutrition scientist, 2011)*

Corroborating the above comment, Jacob (plant geneticist, 2011) remarked that publishing in English is not always appropriate and should not be pursued across all areas of agricultural research: "Some types of results are not of interest to the international scientific community". In these cases, as in much of *in situ* research, national journals with good impact factors should be given priority.

4.7.2 The 'publish or perish' culture

Researchers reported that the pressure to publish as many papers, as quickly as possible, has increased in Brazilian agricultural research over the years. In order to sustain and to further their careers, pursuing publications has become a large part of the work of researchers:

> *If you do not publish, you are no one in science. Even in a public research organisation like this, you are governed by the commandment of publishing. Publications are the 'currency' in the scientific market. (Alicia, plant pathologist/molecular mechanisms of tolerance to stress, 2011)*

Most researchers understand, however, that the pressure for publishing is part of the scientific system as a whole. Not only are research organisations affected by the pressure to publish quickly and often; universities and any sorts of organisations which develop research are similarly implicated. Colton (molecular biologist, 2011), who is also a teacher on a local university postgraduate course, gave a further instance of this:

> *It is a requirement of the University that I keep publishing a given amount of papers a year. Otherwise I am in danger of losing my position as a Professor and as a consequence, lose students, which are my workforce at the moment.*

The three main reasons why agricultural researchers pursue publications is to build a reputation and be recognised in the field; to progress in the professional career; and to be competitive when applying for funds and resources. Tiffany (plant geneticist, 2011) explained the last aspect:

> *Researchers pursue scientific publications because they need to get funds for research. This is usually made through a very competitive process in which publication records are given the highest importance. Besides, the more you publish the more recognition you get. It gives status and prestige.*

Several researchers mentioned career progression inside the organisation as a strong motivational factor for publishing. Adele (soil and plant nutrition scientist, 2011) was one of them:

> *I believe one of the most important factors is the current performance evaluation system. As a researcher, I need to produce a certain number of papers a year so as to progress in my career.*

The following comment, by Lindsay (molecular biologist, 2011), confirms professional reputation and peer recognition as an important motivation for publishing:

> *My main motivation to publish is to obtain international recognition. It is just to know that my papers are being read, are being useful to someone.*

Other motivational factors mentioned by researchers were: contribution to society; advancement of knowledge; and personal satisfaction. When asked about their motivations, however, many researchers referred to a combination of the factors listed above, as can be seen in the following comment by Israel (soil and plant nutrition scientist, 2011):

> *The major motivation is to get my work known. And of course, there are professional development reasons: I need to publish to get a good assessment evaluation, get rewarded and advance in my career. But surely*

> *the main motivation is to transfer this knowledge to other researchers in the field.*

Time constraints were indicated by researchers as the most common barrier to publishing. Franklin (plant pathologist/molecular plant-pathogen interactions, 2011) and Frederick (plant pathologist/computational modelling, 2011), for instance, were discontent with the time they had available to read and write. In accordance with this, protected time to write, peer encouragement and a more relaxed internal peer-review process emerged as the most common requirements of researchers, in support of scientific communication.

Israel (soil and plant nutrition scientist, 2011) commented that the 'publish or perish' imperative influences the patterns of citations in scientific papers. With the pressure to publish and to attract citations at the same time, authors avoid citing older papers, even when they are referential: "It is like a code of practice to keep citing researchers who are still producing and thus, can benefit from their names being cited" (Israel, soil and plant nutrition scientist, 2011). He argued that the reasoning that 'publishing more leads to increased funding and increased funding to more publications' produces undesired effects in the science communication system:

> *Production of scale does not fit science. For instance, if I publish only one paper during my whole career that is highly relevant, wouldn't it be more important than publishing hundreds of papers with no quality at all? In my opinion, the logic of economies of scale work well for several businesses, but not for research organisations or universities. It is nonsense. (Israel, soil and plant nutrition scientist, 2011)*

Applying the 'publish and perish' philosophy to agricultural research is also inconsistent with the fact that many research outputs (particularly of *in situ* research) do not take the form of journal articles, but that of technology transfer communications. Paradoxically, funding agencies value scientific articles more than the other types of communication:

> *There is a strong pressure from the funding agencies for the dissemination of research results through scientific publications. The process of research funding by the Cnpq (National Council for Scientific and Technological Development), for example, is totally based on scientific production records.*

> *But in agricultural research, we often produce results which are more appropriate for technical dissemination to rural or industrial workers than to research peers. (Angelica, natural resources scientist, 2011)*

Eventually, the pressure for publishing is detrimental for the beneficiaries of the agricultural research system, as explained by Israel (soil and plant nutrition scientist, 2011):

> *Some agricultural science specialisms are eminently practical; they are directed towards the productive sector. In this case, communicating results in a merely academic way is not appropriate. Producing a paper is not appropriate. But because of the pressure to publish and the merit and reward system, people prioritise producing a scientific paper which sometimes will never be cited. The audience which really need that information, which is the farmers, are excluded from the process.*

In Michael's (plant pathologist/biological control, 2011) opinion, the pressure to publish and increase scientific records produces an emphasis on numbers, instead of quality of communication:

> *Many people publish just to raise their profiles, fill up their CVs and be competitive when applying for funds. They wouldn't care for quality; just numbers.*

On the other hand, journals' policies and quality requirements are also becoming more stringent over time. With that, having papers accepted for publication is becoming increasingly more difficult. Colton (molecular biologist, 2011) gave an example from his own experience: "In the past, just running some microsatellite gels yielded a good paper; it is not like this anymore".

4.7.3 The internal peer-review system of scientific communications

Embrapa has established an additional mechanism of quality control of scientific publications, which is an internal peer-review process prior to submission of manuscripts to external editorial boards. This is a relatively recent process, coordinated by the Local Publications Committee (CLP, in Portuguese) inside the Research Units. Lindsay (molecular biologist, 2011) explained that the initiative helps

to keep track and control the quality of the organisation's scientific production, as well as to prevent the release of sensitive information:

> *All sorts of scientific communication are examined by the CTI and the CLP, including manuscripts for Embrapa's Technical Series. The Technical Committee observes whether the work exposes sensitive knowledge of any kind and, if there is no problem, the manuscript is approved for external submission. If any problem is found, authors are called to discuss the intellectual property issues, patenting process, and scientific communication strategy.*

Alan (plant pathologist/molecular plant-pathogen interactions, 2011) reinforced the relevance of the internal peer-review process as a means of ensuring that manuscripts are not revealing any sensitive information, especially when industry is involved and intellectual property is an issue:

> *There is a major concern about information protection, particularly in research projects like mine, which involves industry partners. There is a certain caution towards sensitive information. As a researcher, I am not allowed to say everything I want to say. Information to be disseminated needs to be discussed with the competent committee beforehand.*

However, there is much debate about the usefulness and effectiveness of an internal peer-review process prior to submission of papers to external evaluating boards. As a result, although formal guidelines exist, each Research Unit operates this process in slightly different ways, according to Adele (soil and plant nutrition scientist, 2011).

One of the reasons why a group of researchers find the institutional peer-review system inefficient is to do with identifying suitable internal reviewers. Given the current complexity and diversity of scientific approaches and methodologies, the CLPs struggle with assigning an internal referee for every manuscript being produced:

> *The internal peer-review process is extremely unpleasant. Depending on the research area, it is very difficult to identify a suitable reviewer inside the organisation. Many don't have the necessary expertise to evaluate the manuscript. Besides, it is redundant, since the scientific journal has its own peer-review mechanism. (Angelica, natural resources scientist, 2011)*

Luke (genomics/proteomics scientist, 2011) corroborated Angelica's opinion that the internal peer-review process is excessive and unnecessary, since every journal or conference has its own peer-reviewing process:

> *To me, the whole story of the Publications Committee is absolutely nonsense in the current context. It would never keep up with the demand, if taken seriously. I think it is useless because the journals already do this with much more effect, in their peer-referring process. At Embrapa and maybe even in Brazil as a whole, it is a struggle to find many research fellows in a position to judge my work.*

Besides, as Frederick (plant pathologist/computational modelling, 2011) said, the CLPs would not be able to cope with the amount of publications being produced anyway.

4.7.4 The recognition and reward system as trigger for competition

Traditionally, the system of recognition and reward in science is based upon contributions made through scientific publications. Merit and reward, simply put, is given to individuals whose contribution is validated in peer-review judgements.

At Embrapa, the contribution of individual researchers is formally assessed and rewarded on an annual basis; rewards coming in the form of financial awards or salary promotions. Although the outcomes and outputs of agricultural research can be diverse, numbers of scientific publications and citation rates are still the main criteria for the allocation of resources and funds and the mechanism of performance evaluation and reward of individual researchers:

> *In the contemporary science system, decisions about research funding, merit and reward are considerably based on scientific production and citation records (Michael, plant pathologist/biological control, 2011).*

The 'emphasis on academic impact', in the corporate merit and reward system, is a reflection of the current, competitive science system:

> *The problem is that, when the 'publish or perish' culture began to operate, it influenced the internal reward system and publication records became*

> *crucial. One cannot get funds for research without a certain number of high impact publications. (Eric, natural resources scientist, 2011)*

At the time of the interviews, however, a heated debate was taking place at several levels of the organisation, as to whether the logic of the traditional merit and reward system — where scientific records are central — is still appropriate to the current context of agricultural research[56]. A common criticism was the exaggerated focus (of the merit and reward system) on the individual contribution of researchers, despite the current pressure for collaboration in research. Instead of encouraging cooperative efforts, Merton (information systems scientist, 2011) argued, the system incites competition:

> *The current process of individual evaluation and reward reinforces competition instead of collaboration amongst researchers. It rewards quantity, not quality.*

Margaret (molecular biologist, 2011) reinforced Merton's opinion that the recognition and reward system emphasises numbers instead of quality of research outputs. For her, it does not appreciate the impact of the results being generated, which is inconsistent with the growing demand for accountability in research. Colton (molecular biologist, 2011) gave a practical example:

> *The current recognition and reward system does not appreciate the impact of results. With that, a researcher may get rewarded for launching a new variety of soybean, for instance, without that variety being ever adopted by the market. It is a problem in the current system.*

Robert (knowledge manager, 2011) remarked that, through focusing on numbers of scientific publications, the corporate merit and reward system discourages innovation:

[56] During the interviews, efforts were on course by Embrapa's headquarters to the formulation of an alternative mechanism of performance evaluation and reward, which would be tested soon.

> *The whole system is perverse in this sense: more quantitative and less qualitative. When you talk about innovation, you want to see a new product being generated and adopted by the market. The market does not adopt a paper. The scientific publication must accompany the product, but it does not replace it. Our core business is innovation, but then people forget the product and focus on publications.*

He went on to say that the system makes people avoid taking risks, tackling uncertainty, and facing complex problems:

> *In a context where numbers of scientific papers published is the most important currency, people avoid taking too many risks. They go for those things that they are certain can be achieved with their research and will result in publication afterwards. Many times, these things have little impact (if any) in the market and do not answer the big challenges presented to agricultural research in present uncertain times. (Robert, knowledge manager, 2011)*

Colton (molecular biologist, 2011) agreed that risk-taking is not supported by both processes of research funding and recognition and reward:

> *Uncertainty is part of our business as a research organisation. If we don't take risks, who will, for the sake of innovation? But research involving high levels of risk doesn't get funding nowadays.*

The fact that a researcher either coordinates a research project or develops activities in projects run by colleagues also seems to trigger competition, given that the merit and reward mechanism takes project coordination as a more valuable activity than participating in colleagues' projects. Madeline (genomics/ proteomics scientist, 2011) expressed concerns with this:

> *If you don't coordinate a research project, you don't have funds to improve the lab and to develop new research ideas. Also, you don't supervise many students and don't publish enough to compete with your fellow researchers. You stand outside in the knowledge production process in your area of expertise.*

With that, researchers feel pressured to have their 'own' research projects — the ones they will coordinate and through which funds and resources will be injected into their

Research Units (Angelica, natural resources scientist, 2011). However, no one can be a leader all the time: researchers are constantly switching positions between that of a research coordinator and collaborator in many research projects:

> *I understand that nowadays every scientist needs to coordinate research projects but to do so he needs other scientists' participation. In the same way, these other scientists are going to need collaborators in their research projects. You contribute your expertise and you take advantage of other colleagues' expertise at the same time. (Alan, plant pathologist/molecular plant-pathogen interactions, 2011)*

For *in vitro* researchers, besides chasing their 'own' research projects, building and running their 'own' laboratory is also a common aspiration. Due to the prestige and recognition it provides, leadership in the laboratory is an additional trigger for competition (Alan, plant pathologist/molecular plant-pathogen interactions, 2011).

Christian (plant pathologist, 2011) agreed with this, and said that although many people want to collaborate, "there is still a trend towards competition; everyone wants to lead their 'own' research projects, not to collaborate in colleagues' work". In fact, the majority of researchers acknowledged 'competition' as an important force in shaping the ways agricultural researchers relate to one another. Adele (soil and plant nutrition scientist, 2011), for example, said:

> *I believe there is an inherent competitive relationship among agricultural researchers, even from the same organisation. […] Competition, instead of collaboration, governs many of the work-relationships here.*

Megan (post-harvest physiologist, 2012 - validation stage), who took part in the validation of the data analysis, reinforced that competition is central to the research culture at Embrapa:

> *Research Units are told to collaborate among themselves, but there is competition! So, the whole system creates an organisational culture where competition is central.*

Eric (natural resources, 2011) explained that competition exists not only inside the organisation but in several instances of the agricultural research system in Brazil. He exemplified by saying that both the Ministry of the Environment and the Ministry

Agriculture, Livestock and Food Supply develop research activities in genetic resources and biodiversity characterisation, competing for funds and resources from the government budget. For him, mandates of each Ministry are not clear, causing redundancy and waste of public money. Similarly, Embrapa's Research Units compete among themselves (section 4.4.5), as do laboratories, research teams, and individuals.

When asked about the paradoxical relationship between collaborative (previously discussed in section 4.5.3) and competitive forces (see also 4.4.5) in agricultural research, one long-standing researcher at Embrapa made an insightful comment. In his opinion, although Embrapa has grown as an organisation, somehow it sends conflicting messages to its researchers. The first one is that, to be able to satisfactorily respond to the current, complex problems, multi- and transdisciplinary, collaborative teams need to be formed. The second message is the one that comes through the established systems of performance evaluation, merit and reward, which encourages individualism and competition among Research Units:

> *The first message is straight-forward: people need to network. They need to collaborate. This is the first message that comes from the organisation head offices. On the other hand, the organisation employs an individual performance evaluation system which contradicts the call for collaboration. It is an individualistic and quantitative system. Research Units compete among themselves; researchers compete among themselves. The evaluation system does not stimulate any kind of collaboration or synergy. I mean, the organisation, itself, is confused in this situation. There is a contradiction here. And this is a complex issue that I believe will be sorted in the future. Unfortunately, we are still far from finding a solution. (Corey, plant geneticist, 2011)*

In the validation of the data analysis, George (plant geneticist, 2012 - validation stage) explained that, although many efforts are made to neutralise the competition among researchers, "competitive forces still prevail, because of the current system of individual recognition and reward". Megan (post-harvest physiologist, 2012 - validation stage) confirmed the managerial systems adopted by Embrapa to assess and reward the contributions of Research Units and researchers as important triggers for competition at Embrapa:

> *The practice and the discourse are completely different here. So, the organisation instructs researchers to collaborate, but it evaluates them individually. The impact of this is underestimated at Embrapa. In a few words, it seems that success in one area depends on failure in the other!*

George (plant geneticist, 2012 - validation stage) made an important association between managerial systems and non-collaborative information culture at Embrapa. In his opinion, the competitive mechanism of funds allocation, together with the processes of performance evaluation and reward (of both Research Units and individual researchers) are the main aspects influencing the attitudes of researchers towards information and knowledge sharing.

4.8. Summary

This chapter has presented the findings of this study. The notion of a system — comprising inputs, a transformative process, and outputs — was used to organise the narrative. At the macro-level of analysis, a set of system-wide properties was identified that brings form and cohesion to the broad domain of agricultural science, defined as a systemic and application-oriented research framework, concerned with understanding complex natural systems and balancing food production with environmental constraints.

At the meso-level, however, variation in the practices of researchers shape different epistemic cultures, which were found to relate to the type of experimental settings — *in situ*, *in vitro,* or *in silico*. The outcomes produced by research, the groups of beneficiaries it seeks to serve, and the level of engagement of these groups in the research process are examples of differences found across *in situ*, *in vitro* and *in silico* agricultural research. **Table 4** summarises the differences found across the three epistemic cultures.

Table 4. Differences found across the epistemic cultures of agricultural research.

Feature	Epistemic cultures/experimental settings*		
	in vitro	*in situ*	*in silico*
Outcomes of research			
Processes	+	+++	++
Products	++	++	++
Scientific knowledge	+++	+	++
Beneficiaries of research			
General audiences (in special farmers and technicians)	+	+++	++
Research peers	+++	+	++
Focus of research			
Local development and support to farmers	+	+++	+
Commercialisation and profit	+++	+	+++
Research outputs			
Technical publications directed to farmers	+	+++	+
Participation in conferences	++	++	++
Scientific articles	+++	+	+++
Common partners and types of collaboration			
Farmers, participatory research	+	+++	+
Research peers, cross-institutional scientific collaboration	+++	+	+++
Focus of international collaboration			
Knowledge sharing/transfer, South-South partnerships	+	+++	+
Knowledge advancement, North-South partnerships	+++	+	+++
Audiences of scientific publications			
Local public (in Portuguese)	+	+++	+
International public (in English)	+++	+	+++

*Amount of '+' means emphasis.

Agricultural research problems have become more 'complex' over the years, as researchers began to face conflicting demands from different stakeholders, e.g. small farmers and large landowners. To cope with increasingly complex research challenges, collaborative, multidisciplinary research is being required, commonly involving cross-institutional and international networks.

Societal audiences are influencing the choice of research topics and more actively participating in the knowledge production process. With that, there is an increasing pressure for accountability and quality control of research, as well as a growing emphasis on communication and experience exchange — within the scientific community and beyond.

As the sources of funding for agricultural research have diversified over the years, the emphasis on steering research priorities has also intensified. Growing participation of the private sector produced an increase in the commercial exploitation of research, with a strengthened focus on management techniques and business concepts.

A tension between collaborative forces on the one hand and competitive forces on the other was found to permeate and underpin several aspects of the agricultural research

system in Brazil. Researchers engage in collaborative arrangements in order to be successful in contemporary agricultural research, but at the same time they compete among themselves so as to obtain funds and resources for their research, achieve academic recognition and be rewarded by their institutions. The tension between collaboration and competition was found to influence the relationships between research departments, laboratories, research groups and individual researchers at Embrapa, affecting the ways agricultural researchers cope with 'information-as-thing', '-as-process', and '-as-knowledge'.

It was shown, for example, that information about research projects (both completed and ongoing) and human resources from across the organisation is not easily available, which hinders new research partnerships and cross-departmental collaborations. Besides, there are difficulties with the management of 'information-as-thing' and the sharing of 'information-as-knowledge'; fragmentation of roles and responsibilities concerning IKM; divergence of vocabulary and meaning; and an absence of formal policies and guidelines. **Figure 18** is a pictorial representation ('rich picture') of the main themes, issues, and institutional relationships observed at macro- and meso-levels of analysis.

The significance of the empirically observed macro- and meso-properties of agricultural research, in the context of information governance at Embrapa, is discussed in the next chapter, in light of the relevant literature.

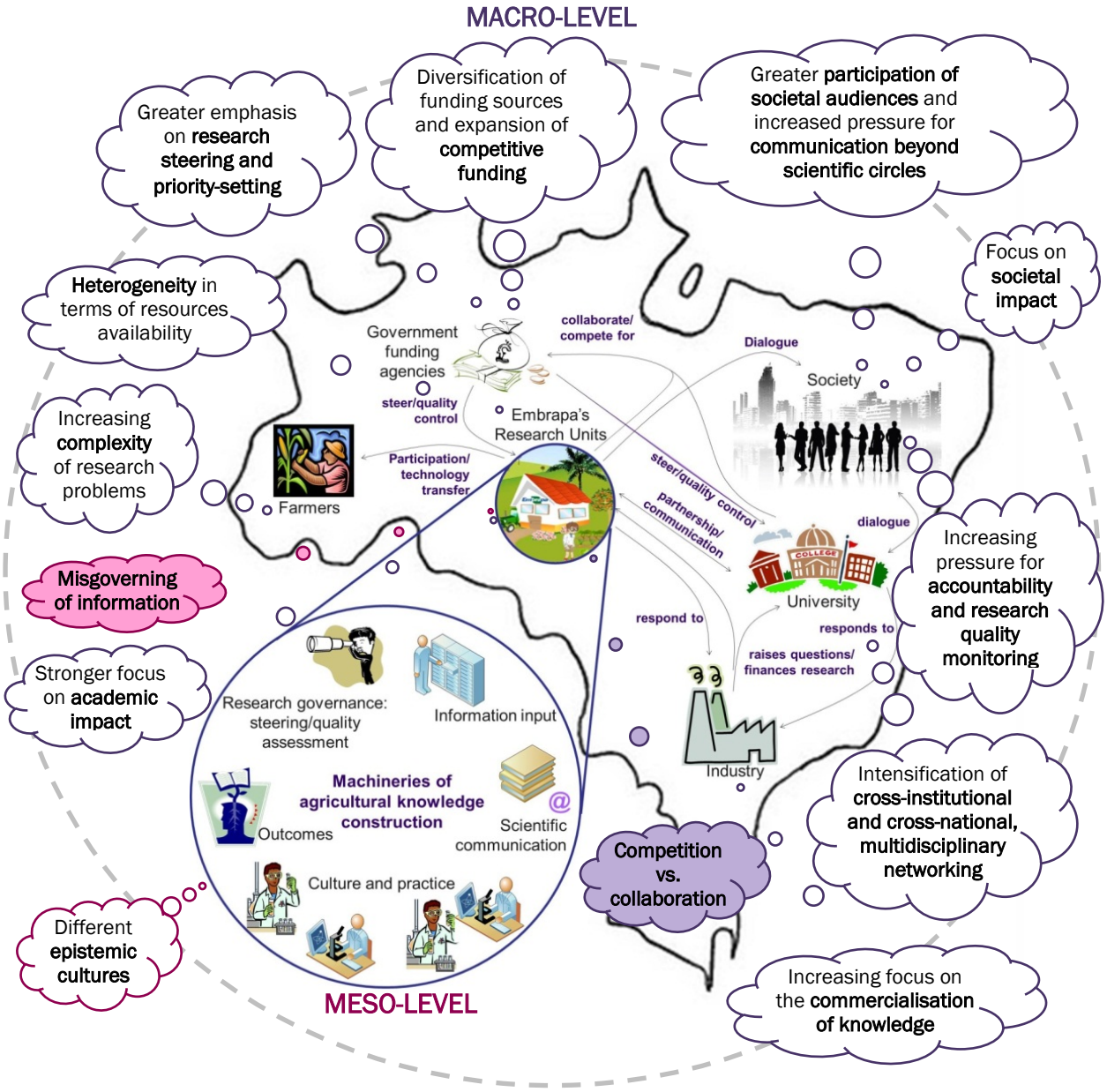


Figure 18. Rich picture of the structured problem situation (post-analysis), showing macro- and meso-level observations.

Chapter Five. DISCUSSION

We must learn to live with contradictions, because they lead to deeper and more effective understanding.

(Teller, 1998, p.1200)

5.1 Introduction

This chapter explores in more detail the empirically observed macro- and meso-properties of agricultural research and their interrelationships with information governance (IG) at Embrapa, in light of the relevant literature. The discussion that follows, therefore, meets Research Objective 3 of this thesis, which is: 'To explore the relationship between the wider agricultural research system, the local practices and culture of agricultural knowledge production, and the governance of information in a Brazilian public research institute'.

The discussion is structured around the themes from the data analysis that represent system-wide ('macro') properties of agricultural research in Brazil. Some of these properties are of an epistemological nature and indicate an imperative (and the gradual development) of a more open, collaborative system of agricultural knowledge production. These are: the focus on societal impact; the increasing complexity of research challenges; the transcending of disciplinary and institutional boundaries; and the greater engagement of societal audiences (section 5.2). Another set of macro-properties relate to managerial aspects of agricultural research: the expansion of competitive funding; intensification of research steering; increasing focus on the commercialisation of knowledge; pressure for accountability and research quality monitoring; focus on academic impact; and heterogeneity in terms of physical and human resources availability). These macro-conditions, which create competition between departments, laboratories and individual researchers at Embrapa, are discussed in section 5.3.

Section 5.4 examines the phenomenon that arises from the cumulative and synergistic effects of all system-wide properties: a pervasive and paradoxical relationship between collaborative and competitive forces in Brazilian agricultural research. Special consideration is given to the effects of the juxtaposition of collaboration and competition for IG at Embrapa. Differences at the meso-level of analysis (between the

epistemic cultures named *in situ*, *in vitro*, and *in silico* research) are discussed throughout the chapter, where relevant. A summary of the chapter is provided in section 5.5.

5.2 Epistemological aspects of agricultural research: the imperative for collaboration

In the following subsections, epistemological aspects of Brazilian agricultural research are discussed in the context of IG at Embrapa. Seen from a macro-perspective, these factors indicate a need for (and gradual development of) a more open and collaborative system of agricultural knowledge production. At a meso-level, however, *in situ*, *in vitro*, and *in silico* research respond differently to the pressure for collaboration. Correspondingly, researchers from the three traditions differ in their attitudes of searching and sharing information (-as-thing and -as-knowledge), which adds complexity to the governance of information.

5.2.1 Outcomes and types of knowledge produced by the different epistemic cultures: implications for information sharing

Agricultural science was characterised in *Chapter Four* as a broad, application-oriented research framework. It was seen that, more than theory development, real world problems in agriculture are the central concern of agricultural research. Across the epistemic cultures of agricultural research, however, differences were found in relation to the beneficiaries served, the nature of the knowledge produced, and the distance between research activities and the uptake of results into the actual practice of agriculture.

In terms of the beneficiaries served, for instance, it was found that while *in situ* research is directed at farmers, agents of supply chains and rural technical assistants, the main beneficiaries of *in vitro* research are members of the research community. These differences are associated with the type of knowledge produced by each epistemic culture, which has an effect on researchers' attitudes towards the sharing of both, 'information-as-thing' and 'information-as-knowledge' (Buckland, 1991).

In situ research can be associated with the 'hard-applied' disciplinary grouping of Becher (1987), in that these researchers are using and developing knowledge that is

purposive and pragmatic, resulting in an agricultural product (e.g. a new soybean cultivar) or technique (e.g. a new way of planting, irrigating, fertilising or managing the soil, so as to minimise the occurrence of a certain plant disease). Given that research projects from this epistemic culture usually culminate with the development of agricultural products or techniques, the impact of *in situ* research (e.g. soil science) on society is sensed almost immediately. The knowledge produced by *in vitro* research (e.g. molecular biology), on the other hand, takes longer to be translated into a practical application for agriculture and to have an impact on society. Focusing on discovery and explanation, *in vitro* research produces cumulative and atomistic knowledge — hence identifying with the 'hard-pure' disciplinary grouping of Becher (1987), otherwise known as 'blue skies' research.

It was shown, however, that even when hard-pure research efforts are carried out at Embrapa, there is a strong prospect that the outcomes will contribute to the solution of problems in the practice of agriculture. This aspect of *in vitro* research is much in line with the conceptualisation of Strategic Research, defined by Irvine and Martin (1984) as 'use-inspired' basic research — that is, research that is carried out "with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of recognized current or future practical problems" (Irvine and Martin, 1984, p.4).

Regarding the nature of the knowledge produced and the impact on society, therefore, the *in vitro* and *in situ* epistemic cultures are at different ends of the same spectrum. Whereas both are focused on real world problems in the practice of agriculture, the impact on society is much more immediate in *in situ* research, compared to *in vitro* research. According to whether *in silico* research involves the simulation of experimental conditions of the field or the laboratory, its impact on society will be sensed more quickly or less quickly. The type of knowledge produced, likewise, will correspond to that of *in situ* or *in vitro* research. This 'chameleon' property of *in silico* research, identifying either with *in vitro* or *in situ* features depending on the researcher's will, turns this epistemic culture very difficult to distinguish.

The cumulative nature of the knowledge produced makes *in vitro* research the most individualistic epistemic culture of agricultural research at Embrapa. Researchers that develop *in vitro* research are highly protective of the knowledge they have worked hard

and long for, and sharing information ('-as-thing' or '-as-knowledge') beyond the research project domain represents a risk that must be avoided, so that priority in scientific discovery and intellectual property rights are secured. This is intensified by the slowness of the processes of intellectual property protection in Brazil. The reluctance of *in vitro* researchers to share information, therefore, has an epistemological explanation. This cultural trait competes with institutional interests, however: increasing the sharing and effective management of 'information-as-thing' (research data, for instance) is desirable in order to add value and extend the useful life of datasets.

In situ research has a different set of cultural characteristics. The knowledge generated is of practical use in the short term, producing an immediate effect on society. Accordingly, *in situ* researchers show less concern about disclosing research data.

From these reasons, it becomes clear that *in situ* research is more conducive for information sharing — of both 'information–as-thing' and '–as-knowledge' — than *in vitro* and *in silico* research. However, due to the lack of incentives and clear guidelines concerning information management at Embrapa, sharing information beyond the limits of a research project is not part of any of the epistemic cultures of agricultural research — though it would be more natural to *in situ* researchers.

5.2.2 Increased complexity in agricultural research: associations with information governance

The challenges faced by agricultural research have grown in complexity over the last forty years — a development that affects the three epistemic cultures to a similar degree. This trend was found to be associated with a set of interrelated developments: the internationalisation of agricultural markets, the growing demand for food, the progressive diversification of food habits and preferences worldwide, and the increase in public awareness of the environmental impacts of agriculture.

A parallel can be traced between the complexity of agricultural research challenges — previously noted by Christiansen and Hunt (2000), Valentine (2005), and Carvalho (2006) — and the current problems of society. As Klein (2004) argued, the contemporary societal problems are dynamic phenomena with strong elements of

uncertainty and interdependency. As a matter of fact, the most complex problems for agricultural research are those at the interface between the natural world and social systems. These multifaceted problems often embody conflicting demands, introducing high levels of uncertainty and tension into the process of knowledge production. An example is the increasing demand for food: meeting this demand might entail an expansion in the area planted, which is undesirable from an environmental perspective, thus requiring negotiation and accommodation of interests among the different groups of beneficiaries of agricultural research.

The need to tackle complex problems in a way that accommodates the interests of a varied audience has caused a change in the profile of agricultural researchers from the three epistemic cultures — *in situ*, *in silico*, and *in vitro* research. To resolve conflicts of interest among stakeholders, researchers have had to develop negotiation skills, broaden their roles and extend their responsibilities beyond experimental settings. Securing the necessary financial, physical, human, and information resources for their work has also demanded a range of new skills — such as people, resources, risk, and project management — which are not covered by the traditional training of researchers. This fact corroborates previous work by Barbercheck *et al.* (2011), that identified important gaps in the traditional training of scientists whilst investigating organic agriculture research in the USA.

As the roles and activities performed by Embrapa's researchers have progressively diversified in response to the increased complexity of research, so have their needs of 'information-as-thing'. This confirms the current understanding that a person's information needs depend on the task they are required to perform and the nature of available knowledge (Hjerland, 2002; Case, 2007). The progressive diversification in the types of information needed by agricultural researchers is, therefore, a reflection of the increasing complexity of research problems. This supports Bystrom and Jkrvelin's (1995) findings that, as task complexity increases, the complexity of the information needed also increases, requiring a greater number of sources of information and diversification of channels.

Accessing information and data from previous research via refereed scientific journals, for instance, does not satisfy all of the information needs of researchers at Embrapa anymore. Given the fast pace of scientific development, accessing research-related

information that has not been published yet (e.g. about ongoing research projects) became critical. To meet this need, informal communication networks — composed of professional and personal relationships developed over time — have grown to comprise an important source of information, which confirms previous assertions that much of the information needs of scientists are met through contact with colleagues at conferences and in the workplace (Case, 2007).

As task complexity have increased in agricultural research, varied information of a 'non-scientific' nature became required in the daily practice of researchers, particularly in relation to geography and general statistics (political and social issues), patents and intellectual property (economic issues), and law and biosafety (legal issues). Providing support for this broad range of information needs, however, is beyond the current service provision at Embrapa. As a result, researchers have had to develop the necessary skills and learn by themselves where and how to obtain the information they need in a varied range of electronic information services, becoming confident, independent information seekers. Concurrently, face-to-face interactions, personal acquaintances, and virtual exchange of personal communication became ever more crucial for agricultural researchers, as sources of information of both a scientific and a non-scientific nature. This fact illustrates the central role of the 'invisible colleges' in agricultural research — the small, closely coupled core groups of leading researchers that maintain "continual contact with each other in order to monitor recent developments in the area and adjust their activities accordingly", as popularised by Crane (1971, p.585). The growing role of informal communication in the practice of agricultural researchers was also verified by Majid *et al.* (2000), in a study covering the information needs and seeking behaviour of agricultural scientists in Malaysia.

Invisible colleges are highly elitist, exclusive (only prestigious researchers are part of), and competitive (Fuchs, 1993), though. That is why there are still complaints that internal communication flows are poor or obstructed at Embrapa — especially horizontally (between individuals from the same department and across departments), but also vertically (from superiors to subordinates) and upward (from subordinates to superiors). Aware of this problem, and due to the little convergence of information systems, efforts have been made to develop appropriate digital information systems that will assist the access to and the sharing of information ('-as-thing') inside the organisation.

The geographical distribution of Embrapa's Research Units across the Brazilian territory might well explain part of the difficulties with internal communication, but is certainly not the only reason. The poor levels of internal communication — particularly among *in vitro* researchers — comprise one element of the information culture and give indication that the inadequacy or absence of information services in support of research is not merely an IT problem, but one that has deeper roots.

Nevertheless, IG is approached at Embrapa with a strong technological bias. From the senior management perspective, there is an expectation that IT can solve most problems related to information and, at the same time, there is little awareness of the cultural forces that might influence researchers' attitudes toward information. Borrowing Davenport *et al.*'s (1992) political metaphor, it can be said that, at Embrapa, information is governed as in a regime of 'Technocratic Utopianism'. Under such a regime, there is "an underlying assumption that technology will resolve all problems and that organizational and political issues are nonexistent or unmaneageable" (Davenport *et al.*, 1992, p.55). Amongst the organisations they studied, Davenport and Prusak (1997) found Technocratic Utopianism as one of the most common models of 'information politics' (which they interpreted as equal to 'information governance'), either on its own or alongside another model. At Embrapa, Technocratic Utopianism is coupled with Feudalism, which is discussed later in this chapter (section 5.3.4).

5.2.3 Transcending disciplinary and institutional boundaries: dynamic research coalitions

Agricultural science is traditionally depicted as a multidisciplinary field, as the following definition by Oberle and Keeney (1991, p.4) shows:

> *[Agricultural science is] a complex and multidisciplinary field that represents the vital link between human (socioeconomic) systems and the natural environment.*

Evidence was found, however, that this has not always been the case in Brazil. Forty years ago, agricultural knowledge was mainly produced from a disciplinary standpoint and researchers worked mostly in an isolated fashion. Over the last three decades, though, as the challenges for agricultural research became too complex to be handled

from a mono-disciplinary perspective — involving too many factors, which are interrelated in too many ways — collaborative, multidisciplinary research efforts became dominant.

Multidisciplinary research appears to have become pervasive not only in agricultural research but in diverse areas of scientific interest (Garwin, 1999; Harvey *et al.*, 2002; Wollenweber *et al.*, 2005; Lopez Jr. *et al.*, 2007; Kalluri and Keller, 2010; Barbercheck *et al.*, 2011). Harvey *et al.* (2002), for instance, acknowledged and situated multidisciplinary research as a crucial element of the intricate practices of contemporary medical research. In their opinion, handling highly complex problems demand specialisation; and "specialisation, if wider questions are to be addressed, requires collaboration" (Harvey *et al.*, 2002, p.767).

Taking advantage of the digital technologies and of reduced travel and transportation costs, agricultural researchers are indeed increasingly engaged in collaborative arrangements. These are, most commonly, multidisciplinary, temporary-based and situation-driven configurations. Due to the continuous creation, dissolution, and recreation of new partnerships, a more appropriate designation for the collaborative arrangements of agricultural researchers would be 'coalitions', i.e. temporary alliances for joint action, mutual assistance and protection. In other words, these coalitions are the joining together of specialists, disciplines, departments, and institutions for a limited time and particular purpose (e.g. being competitive in a research call, solving a complex problem). Frequently, the collaborative team splits up after reaching the desirable or a reasonable result. In this respect, there is considerable agreement between this research's findings and Mode 2 knowledge production, in which research groups are said to be less firmly institutionalised: "people come together in temporary work teams and networks which dissolve when a problem is solved or redefined" (Gibbons et al. 1994, p.6).

Commonly, the coalitions of agricultural researchers transcend institutional boundaries, involving a range of public and private organisations, and, every so often, international partners. This is due to the fact that many of the complex problems faced by agricultural research nowadays have an international character and cannot be tackled from a purely national perspective (e.g. those related with food sustainability, security and the environment).

The international dimension of recognition in science is widely known: scientists seek worldwide recognition for their discoveries and disseminate results in international journals and conferences. What was observed at Embrapa, however, corroborates the claims from the theorists of the Postacademic Science that "science is 'going international' in a big way" (Ziman, 1994, p.217).

The proliferation of cross-institutional, national and international networks was also identified as a feature of Mode 2 Knowledge Production, facilitated by advances in ICT and reduction of travel costs (Gibbons *et al.*, 1994). In some aspects, however, the dynamics of the networks in which Embrapa's researchers are engaged contradicts the Mode 2 theory. First, they have a strong managerial component and are usually arranged in a hierarchic way — though spontaneously created by researchers. This fact challenges Gibbons *et al.*'s (1994) assertions that collaborative networks would be constituted in a non-hierarchical way; not being planned or coordinated by any central body. A second difference is that, as part of a project team, Embrapa's researchers contribute their own disciplinary perspectives, with limited interaction occurring between partners and across disciplines, thus contradicting the imperative of 'transdisciplinarity' in Mode 2. The researchers acknowledge, however, the relevance of establishing an active dialogue among the different disciplines engaged in the solution of complex problems of agriculture, and indicated transdisciplinarity as a trend for the future.

Interestingly, Aeberhard and Rist (2009) observed a contrary trend, while investigating the production of knowledge for organic agriculture in Switzerland. They found that research is less transdisciplinary and there is now less exchange between researchers and farmers than there was some decades ago. The contrasting results between the present study and that of Aeberhard and Rist (2009) reinforces that the dynamics of knowledge production systems are site-specific, contingent upon wider contexts and specific cultural and social conditions.

Among the epistemic cultures of agricultural research, *in silico* research epitomises the highest level of cross-institutional collaborations. This is clearly due to the centrality of advanced computer technologies to this epistemic culture: regardless of geographic barriers or formal institutional links, collaborative experiments can be easily performed and large datasets shared and analysed in the virtual environment.

In this sense, *in silico* research is closely related to the research culture of Cyberscience (Nentwich, 2003), a term that is defined in relation to scientific activities developed in the cyberspace — "the virtual space created by electronic networks" (Gresham, 1994, p.37).

With regards to the types of international collaboration, differences were also found across the epistemic cultures of agricultural research. For *in situ* research, the most common manifestation of the phenomenon of internationalisation consists of knowledge sharing and transfer projects involving nations of the Southern hemisphere. The most common type of internationalisation involving *in silico* and *in vitro* research, on the other hand, entails North-South collaborations at the cutting edge of agricultural research.

The increasing internationalisation of science has been confirmed by the bibliometric community (Hicks and Katz, 1996; Gornitzka and Langfeldt, 2008) in studies that evaluate the institutional affiliation of authors. Very often, the internationalisation of science is associated with the migration of researchers from their home countries to the big science powerhouses, such as Germany, US, and UK, which justifies transnational co-authorship (Krishna *et al.*, 2000; Laudel, 2005). Knight (2006), Altbach (2007), and Rizvi (2007), on the other hand, linked the internationalisation of science to developments in higher education and the proactive institutional behaviour of universities towards facilitating international education exchange, joint degrees, and cross-national research collaboration. In Brazilian agricultural research, however, since no evidence was found of an increase in the levels of educational exchange or migration of researchers in recent years, the increasing internationalisation of agricultural research is to be interpreted as an epistemic requirement: a consequence of the growth of complexity and scope of research problems. This confirms previous work by Ziman (1994), who indicated the increased scope of research challenges as a motivating factor underlying the growing internationalisation of science, combined with the escalating costs of scientific instrumentation, the global reach of research-intensive organisations, and the rapidly evolving technologies of travel and communication.

While being part of a coalition — as members of a multidisciplinarity, cross-institutional research project — agricultural researchers are keen to disclose information with

partners for as long as the coalition endures. Apart from invisible colleges, which are elitist and exclusive, therefore, research projects are the main units of collaborative work and information sharing at Embrapa. Outside of a project or a formal contract of collaboration, researchers show reluctance to share information and data, as previously discussed (section 5.2.1). This is particularly evident in North-South international collaborations, in which *in vitro* researchers usually engage. In this kind of coalitions, information exchanges are monitored, so as to protect the knowledge produced — usually of a sensitive, atomistic and cumulative nature, as explained previously (section 5.2.1). Collaborations involving nations in the Southern hemisphere, however, have a strong component of knowledge sharing and transfer. They are precisely aimed at information sharing and dissemination.

The findings discussed above reinforce the character of *in situ* research as the most open and collaborative culture of agricultural knowledge production at Embrapa. Other aspects, discussed later in this chapter, give further evidence.

5.2.4 Transcending the boundaries of science: the greater engagement of societal audiences

Societal audiences are more actively participating in agricultural research in Brazil — not only in the setting of the research agenda, but increasingly more in the very process of agricultural knowledge production. This adds heterogeneity and increased reflexivity to knowledge production, facilitating the development of feasible solutions for the real world problems tackled by agricultural research. Even when not actively participating in scientific activities, society as a whole is clearly more attentive to the implications of agricultural research, making their voice heard on the most controversial issues (an example is the heated debate and influence of the public opinion on research with Genetically Modified Organisms).

The emergence of more open systems of knowledge production — discerned by an increase in the levels of public awareness, interest and participation in the scientific activity — is a point of convergence among the conceptualisations of changing research systems. Nowotny *et al.* (2001), for instance, argued that a Mode 2 science system evolves in the context of a Mode 2 society, which exerts strong pressure for science to become more integrated with its social context. Better educated citizenry would place new demands for research and become active agents in the dialogic and

reflexive process of Mode 2 knowledge production. The close association between knowledge production and distribution means that Mode 2 knowledge is produced in the 'context of application'; i.e. problem formulation and solving are not set within a disciplinary framework, but around practical applications, taking into account the interests of a diverse range of actors in complex social and economic contexts (Gibbons *et al.*, 1994).

Knowledge production in the context of application, however, is not a recent development in Brazilian agricultural research, albeit it is growing stronger. This is not inconsistent with the Mode 2 notion, though, since Gibbons *et al.* (1994) acknowledged research in the context of application as an inherent feature of a number of disciplines in the 'applied' sciences, such as chemical engineering, aeronautical engineering, and computer science, among others.

As socially organised groups participate more in agricultural research, communication plays a central role in linking together sites and people around problem-solving. To keep the channels open and foster communication exchanges, a range of services and procedures are being put in place, taking special advantage of ICTs. Many information services that were used in support of research at Embrapa, for instance, have been recently redirected towards external audiences, in response to the increased pressure for communication beyond scientific circles.

The increased levels of communication observed between agricultural researchers and society, with a growing role for informal channels, is in accord with the conceptualisation of a Mode 2 knowledge production, to which "communications in ever new configurations are crucial" (Gibbons *et al.*, 1994, p.6). A trend towards enhanced communication within and beyond scientific circles was also advocated in the conceptualisations of Postacademic Science and Triple Helix (Leydesdorff and Etzkowitz, 1996; Ziman, 2000).

The levels of integration with the social context, however, are not equal across the distinct epistemic cultures in agricultural research. To adopt the terminology of Gibbons *et al.* (1994), there are different levels of 'contextualisation' — the way society speaks back to science. The highest level of engagement of farmers in agricultural research, for instance, occurs with *in situ* research. Being mostly developed in the context of farmers' fields, face-to-face exchanges with the end-users are favoured in

in situ research. 'Participatory research' — a configuration in which farmers become actors in the process of knowledge production — epitomises the highest level of integration between agricultural research and societal audiences. The opposite trend occurs with *in vitro* research, potentially due the physical detachment that is imposed by the laboratory and the technical knowledge involved, requiring from research actors a higher level of science literacy.

Patterns of communication are also variable across the different epistemic cultures of agricultural research. While *in silico* and *in vitro* research values the most the scientific article and formal communication, informal talks in events and several types of technical publications are of greater relevance in the diffusion of *in situ* research outputs. This produces an unresolved tension, however, since communications directed towards societal audiences are less valued in the institutional mechanisms of recognition and reward than scientific communications. Due to its association with managerial aspects of agricultural research, this finding is discussed further in section 5.3.

5.3 Managerial aspects of agricultural research: triggers for competition

The increasing complexity of research challenges was discussed in the previous sections as an impetus of change in the ways agricultural knowledge is produced in Brazil. As collaboration becomes mandatory for the solution of increasingly complex demands, agricultural knowledge production grows into a more open, reflexive, and heterogeneous process. In this process, disciplinary, institutional, and national boundaries are being transcended by agricultural research, with increased participation of societal audiences.

These collaborative forces are confronted with competitive forces arising from managerial aspects of agricultural research in Brazil; particularly, the systems of research steering, funds and resources' allocation, quality control, and recognition and reward. The implications of these aspects for the governance of information are discussed in sections 5.3.1 to 5.3.6.

5.3.1 Diversification of funding sources and expansion of competitive funding

An over-stretched public budget has forced Brazilian agricultural researchers to look for alternative funding schemes from a variety of national and international bodies. The need to raise funds with agencies which devise their own policies, quality assessment and funds allocation mechanisms has introduced added complexity and competition to agricultural research.

This development is not exclusive to Brazilian agricultural research, though. Pohoryles and Cvijetic (2002), for instance, pointed out a sharp relative decrease of institutional core funding in public research organisations in the European research scene, accompanied by increased reliance on competitive funds. A progressive diversification of funding sources for research was also anticipated by the authors of the Mode 2 account (Gibbons *et al.*, 1994). The intensification of competition within research organisations — as an outcome of this development — and its effect on the practice of researchers, however, was not appreciated by Gibbons *et al.* (1994).

Although competition might be generally conceived as relevant for improving scientific performance and impact on society (Fuchs, 1993), too much of it may be dysfunctional from the perspective of scientific productivity, since it "takes time and energy away from research and writing" (Auranen and Nieminen, 2010, p.831). Besides, strong funding incentives may produce an "emphasis on quantity instead of quality, orientation to less innovative, mainstream research and weaker societal impacts in the long run" (Auranen and Nieminen, 2010, p.831). Paradoxically, without contributions to science, measured in terms of numbers of scientific publications and citations, researchers would have difficulties getting funding. And without funding, they would not have the means of intellectual production.

Assessing the competence of research teams on the basis of scientific publication numbers causes particular tension in agricultural research, given the variation in the types of outputs generated by the different epistemic cultures. Common outputs of *in situ* research, such as technical communications directed to farmers, for instance, are not as valued in the competitive system of funds allocation as the scientific article. By overemphasising the scientific article, funding agencies give a certain advantage to *in vitro* research. On the other hand, potential outcomes of *in vitro* research, such as patents — which take a longer time to be achieved — are also undervalued, if

compared to the scientific article. The criteria used by public and private agencies impact on early career researchers the most, given their limited experience and reputation in the scientific community.

A continuous tension between collaboration and competition is then created: tackling the complexity of current research problems requires collaboration between Embrapa's researchers, laboratories and Research Units; while securing the necessary funds for research entails intense competition. Ultimately, this tension creates an internal atmosphere that is unsupportive for 'information-as-process' (Buckland, 1991) to occur, disturbing the flow of 'information-as-thing' and '-as-knowledge' within the organisation, thus imposing difficulties for the governance of information at Embrapa.

The scenario described above demonstrates the close relationship that exists between the general internal atmosphere in an organisation and its 'information environment', of which 'information behaviour'[57] is a fundamental element (Choo *et al.,* 2006). Current research on information behaviour has shown that cultural differences across disciplines influence the ways in which researchers seek and use information (Hjerland, 2002; Case, 2007). Although investigating the information behaviour of agricultural researchers was not among the objectives of this thesis, findings give strong indication that cultural, social and environmental dimensions of research have an influence on their attitudes towards information, corroborating previous studies (Hjoriand and Aibrechtsen, 1995; Spink and Heinström, 2011).

The competitive behaviour that is prompted by the system of funds allocation — which affects *in situ*, *in vitro*, and *in silico* epistemic cultures by the same token — is reinforced by other managerial aspects of agricultural research. These are discussed in the following sections.

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[57] For Pettigrew (1997, p.44), information behaviour is "how people need, seek, give and use information in different contexts".

5.3.2 Intensification of research steering

Priority-setting is a long-standing practice in agricultural research worldwide, as can be noted from early studies of the National Research Council (1977) of the United States of America. Evidence was found, however, that interest in 'steering' agricultural research in Brazil has intensified over the last forty years, concomitantly with the progressive diversification of funding sources. To ensure that research is oriented towards the needs and interests of society, direct beneficiaries and stakeholders, priority-setting grew into an intricate process.

This finding corroborates earlier work suggesting an increased desire to steer research priorities as a distinguishing trend in contemporary research (Pohoryles and Cvijetic, 2002). This trend would operate at multiple levels: the supranational (e.g. the European Community Framework programmes), the national (e.g. dedicated research programmes developed by ministries), and the system-level (e.g. research councils) (Nowotny *et al.*, 2003). In Brazilian agricultural research, however, steering also occurs at the organisational and local levels, by means of research foresight exercises and the participation of societal audiences in topic-choice.

The emphasis of Brazilian agricultural research on foresight activities resembles accounts of Irvine and Martin (1984). The authors of Strategic Research presented the notion of foresight as a policy tool to support the identification of areas of basic research that are beginning to exhibit 'strategic potential'; that is, areas that have constituted a knowledge base that, "with further funding, might eventually contribute to the solution of important practical problems" (Irvine and Martin, 1984, p.7). Strategic Research, they argued, is only partly directed: scientists have a considerable degree of autonomy in setting up the research agenda and research foresight serves the purpose of resolving potential conflicts over priority-setting (Martin and Irvine, 1989). In agricultural research, however, autonomy decreases as research steering intensifies. Researchers have limited freedom in defining their own research agendas and pursuing their 'private' interests. Instead, the definition of problem areas and the choice of research topics follow a highly structured process, in which the main beneficiaries of research and societal audiences play a growing role.

The high level of external influence in the choice of research topics causes tension amongst Embrapa's researchers and Research Units, given that these are organised

according to broader themes. That is, the results of the priority-setting process might favour one Research Unit and not the other, being a source of internal competition and leading to low levels of synergy and partnerships among departments and laboratories. Restricted levels of internal collaboration is maximised by the fact that information about the internal expertise ('who knows what' and 'where' at the organisation) is not easily accessible — which is indicative of a problem with the management of 'information-as-thing'.

5.3.3 Increasing focus on the commercialisation of knowledge

As the participation of the private sector in the financing of agricultural knowledge production increases, the generation of applicable knowledge and its commercialisation is being widely promoted. The increasing commercialisation of research is evidenced in the emphasis on technology generation, innovation and the imperative to exploit 'intellectual property' produced in agricultural research. This development is also reflected as a growing need for information ('-as-thing') concerning patents and all sorts of intellectual property-related issues, as previously discussed in section 5.2.2.

The phenomenon of 'research commercialisation'[58] — typified by a growing reliance on private sources of funding and commercial exploitation of research results, protected in the form of intellectual capital — was anticipated by several of the conceptualisations of changing research systems reviewed in *Chapter Two*. Nowotny *et al.* (2003), for instance, highlighted marketability and commercialisation of knowledge as one of three crucial trends in Mode 2 knowledge production — the other two being increased accountability and steering of research priorities. Likewise, authors of the Academic Capitalism notion acknowledged the growth of market-like and for-profit activities at universities, supported by governments as a way to stimulate economic growth and the diversification of the sources of research funding (Slaughter

[58] Other terms are research 'marketization' or 'commodification'.

and Leslie, 1997). Marginson and Considine (2000), in their observations about the Enterprise University, also noted a general pattern for making the university more like an enterprise. Finally, a growing focus on the utility and profitability of knowledge, resulting from an increased participation of the private sector, was similarly emphasised by the notion of a Postacademic Science (Ziman, 2000).

The increasing commercialisation of knowledge, however, is acknowledged by the conceptualisations mentioned in the last paragraph as a 'general' trend in contemporary research. Contrariwise, examining the actual practices of agricultural researchers shows variation in the intensity and effects of this development across the different epistemic cultures. Technology generation, innovation, and intellectual property issues have become central to *in vitro* and *in silico* research. Most of *in situ* research, however, for supporting local agricultural systems — particularly small farming — has limited potential of generating profit in return. Balancing commercial exploitation of research with supporting local agricultural systems, therefore, is an unresolved tension in Brazilian agricultural research.

The emergence of a more business-like environment and the race for priority in scientific findings (and subsequent commercial exploitation) instigate competitive behaviour among Research Units, departments, laboratories and individual researchers at Embrapa. Due to intellectual property issues and fear of plagiarism, a general atmosphere of distrustfulness is created, which jeopardises open and transparent collaborative relationships. A direct implication of this is difficulties with the sharing of 'information-as-knowledge' and its retention following employees' retirement, particularly *in vitro* and *in silico* researchers.

5.3.4 The pressure for accountability and research quality monitoring

The progressive diversification of entities involved in research steering and funding was accompanied by an increasing demand for accountability in agricultural research. At Embrapa, this was sensed by an intensification of mechanisms of managerial control and the introduction of multi-level monitoring of research quality. This finding corroborates observations by Hemlin and Rasmussen (2006) that closer interconnections between science and society are producing a change from research

quality control into ‘quality monitoring’: stakeholders are more closely involved in research, requiring evaluations to be done on a regular basis.

A trend towards tighter management control of more and more aspects of research is also indicative of how deeply a market culture is affecting agricultural knowledge production in Brazil, as discussed in section 5.3.3. Pursuing commercial development as well as knowledge production, the research organisation looks more like an entrepreneurial organisation, to which business concepts and corporate management techniques are applicable (e.g. performance monitoring, and project, process, and risk management). This confirms Pohoryles and Cvijetic's (2002, p.282) perception that, as soon as commercial interest enters the scene, “science and research are seen as a means of economic growth”.

An illustration of the tightened mechanisms of managerial control at Embrapa is the performance evaluation of Research Units: their productivity, managerial quality and impact are regularly assessed, and results of this evaluation are used to inform decisions on infrastructure investments. To obtain certifications of quality, laboratories are also evaluated, according to international standards. With regards the scientific activity per se, the first instance of research quality control, at Embrapa, is the mandatory process of research proposals discussion within research groups and quality assessment by research peers, before submission to funding agencies. The assessment and monitoring of projects’ execution is a second instance of quality control, entailing the systematic presentation of technical reports and regular meetings with peers and heads of research. When results of a project are ready to be disseminated, a final mechanism of quality control takes place, through an internal peer-review process, prior to submission to the evaluating boards of journals or conferences. Altogether, these macro-observations indicate the beginning of a transition from quality control to quality monitoring; from product to process control, which has been noted by Hemlin and Rasmussen (2006, p.175):

> *Where quality control is concerned, the emphasis is on the end product of knowledge production, whereas quality monitoring is a process that follows and, more important, influences knowledge production from its onset to its conclusion.*

As previously shown, however, current mechanisms of research quality monitoring at Embrapa are still more focused on numbers and financial accountability than on the appropriateness and impact of research outcomes, i.e. new methodologies or products. The emphasis of agricultural research on societal impact, however, requires a new dimension to research evaluation. Also, the mechanisms of research quality control are still internal to the scientific or expert realms.

Although no consensual, acceptable formula has been achieved yet, there is dissatisfaction with the role of peer-review analysis as a central mechanism of quality assessment and performance evaluation in agricultural research. For this reason, different informal rules govern the peer-review process across the Research Units and the dissemination of scientific information follows no strategy in particular.

Several of the conceptualisations of changing research systems reviewed in *Chapter Two* made the case for the intensification of research accountability and the emergence of new forms of quality control, in which segments of society would have a growing role. The Mode 2 conceptualisation, for instance, anticipated a "shift from control located within disciplines to more diffuse kinds of control" (Gibbons *et al.*, 1994, p.33), originated from the increased social pressure for research accountability, i.e. the enhanced "social demand for quality, performance and value for money" in research (Gibbons *et al.*, 1994, p.84). Arguments in support of the Enterprise University (Marginson and Considine, 2000) and Postacademic Science (Ziman, 1996a) accounts also reported the emergence of an imperative for accountability of research, which would gradually replace or bolster the elitism of peer-review with quality control of people, projects and performance. On the same subject, the theorists of Post-normal Science (Funtowicz and Ravetz, 1993) claimed that higher levels of uncertainty would require an extended peer community scheme for assuring research quality: an 'internal' extension of the peer community would occur through the involvement of other disciplines in the process of quality control, while an 'external' extension would entail public participation.

No evidence was found of an 'extended' peer community or increased public participation in the monitoring of agricultural research quality, however — even though quality monitoring has recognisably become a central issue in Brazilian agricultural research and despite the increased levels of interest of the society in the implications

of research. Mechanisms of social control are still unclear or absent. In fact, only two indirect mechanisms of social quality monitoring are present: participatory research, through which farmers are directly engaged in *in situ* research; and consultancies with farmers and agents of agricultural production chains during the process of research agenda setting.

The strengthened mechanisms of managerial control and research quality monitoring and, particularly, the adoption of a linear system of performance assessment across diverse and heterogeneous research settings, exacerbate competition among Research Units. Understanding that information gives competitive advantage, managers of Research Units control their information environments, developing information services that serve their own needs, and reporting limited information to the overall corporation. As a consequence, there are difficulties with accessing information ('-as-thing') about research projects (completed and ongoing) and human resources from across the organisation, as previously noted.

The scenario outlined above identifies with the information politics model named by Davenport *et al.* (1992) as 'Feudalism', typified by a fragmentation of initiatives towards information management across diverse 'realms'. At Embrapa, this fragmentation is sensed in relation to the management 'information-as-thing'. Just like in a feudal regime, managers control their information environments as lords would do — in many separate castles. These 'realms' end up with different languages (conceptual divergence) and information systems, posing difficulties in the access to information ('-as-thing') and causing uncoordinated operation in the organisation as a whole. The organisation's head offices have little control over the situation and the absence of a formal policy or guidelines concerning the management of 'information-as-thing' weakens the overall capability for effective IG.

Extending the framework of Davenport and Prusak (1997) to include the dimension of 'information-as-knowledge', a range of other aspects are identified that confirm Feudalism as a prevailing regime at Embrapa. This can be exemplified with the political and cultural barriers to the implementation of an institutional knowledge management strategy. Although a conceptual model for the knowledge management had already been constructed, high levels of internal competitiveness and weakened central power impeded its implementation. Difficulties with the retention of knowledge following

employees' retirement provide another example — *in vitro* and *in silico* researchers being the ones showing most reluctance to share 'information-as-knowledge', even when leaving the organisation.

The feudal model of IG flourishes in environments of strong divisional autonomy (Davenport *et al.*, 1992), as at Embrapa, with its 42 geographically dispersed Research Units. Feudal actions reduces Embrapa's central power to make decisions based on information, for the common good, and to make decisions about information as well, e.g. how to improve the organisational IG.

If taken as an organisation's conscious choice, however, Feudalism may present an appropriate governance model. Particularly when organisations are comprised of departments which are different in terms of the products they generate, the audiences they serve, performance measures applied, and information needs, Feudalism can provide an interesting framework, allowing a bottom-up approach to the governance of information. In organisations like Embrapa, which need to operate through integrated and collaborative processes, however, Feudalism is most likely to undermine effective IG.

5.3.5 The recognition and reward system: emphasis on academic impact

Despite the growing concern with the societal impact of agricultural research and the increasing levels of private funding, the pressure for academic impact through scientific publications has increased over the recent years. This fact confirms previous observations of a study with Norwegian universities that, even though industrial funding of university research increased, there is no decline in academic outputs; both scientific publications and entrepreneurial results are more frequent (Gulbrandsen and Smeby, 2005).

In order to sustain and further their careers, achieve professional reputation and peer recognition, pursuing publications has become a large part of the work of agricultural researchers at Embrapa. This is because the general funding system and Embrapa's recognition and reward system regard scientific production as primacy.

In fact, the reasoning that publishing in greater numbers leads to increased funding, and increased funding to more publications, produces undesired effects in agricultural

research. Above all, applying the 'publish and perish' philosophy to agricultural research is inconsistent with the fact that most outputs of *in situ* research do not take the form of journal articles, but of communications directed to farmers and rural technical assistants. Participating in projects coordinated by colleagues, rather than being lead investigator in a project, also becomes less advantageous in this scenario. Accordingly, building and running one's own laboratory, for *in vitro* researchers, is more valuable than working as part of a research team. All in all, the emphasis on academic impact elicits individualism rather than collaborative behaviour at Embrapa.

Associations between incentive systems in academic science and non-collaborative behaviour have been made previously by Müller (2012), in a study involving post-doctoral researchers in the life sciences. Understanding individual performance as decisive for their careers, and tenure as a function of the number of publications, the interviewed post-docs stated their preference for single-authored publications above co-authored ones, being restrictive in setting up collaborations.

By focusing on numbers of scientific publications, the Embrapa's reward system discourages not only collaboration, but also risk-taking and the tackling of uncertainty in science. To achieve success in their professional careers, many researchers would rather develop projects in which publishable results can be more easily and quickly obtained.

Patterns of scientific communication amongst researchers at Embrapa give evidence of an additional unresolved tension: the difficult balance between the local and the global dimensions of agricultural research. Current reward mechanisms encourage the publication of results in international journals, even though much of the knowledge produced is only of national/local interest. The "number of international publications is not synonymous with scientific quality" (Auranen and Nieminen, 2010, p.825), though. There is still another antagonistic aspect: even though Embrapa accords high importance to and seems to be positively oriented to commercialisation of knowledge, current management systems continue to assign high importance to publications.

Together with the competitive mechanism of funds allocation, the process of individual performance evaluation and reward instils a non-collaborative information culture. One last aspect that contributes to this phenomenon is described in the next section.

5.3.6 Heterogeneity in terms of physical and human resources availability

The relative geographic position of research institutes in a developing country has an influence on the availability of facilities and other resources to research. In Brazil, inequalities are observable across the territory, in relation to high speed internet connection, communication and transport infrastructure. Realities are also multiple in terms of availability of support personnel and student recruitment capabilities.

Due to a stronger reliance on technological tools, difficulties with physical infrastructure affects mostly *in vitro* and *in silico* research at institutes located in the least developed areas of Brazil. *In situ* researchers experience most problems with technical support personnel — particularly agricultural technicians and field staff. To overcome human and physical resources' constraints, there is an increasing focus on the maximisation of resources for research at Embrapa. However, high levels of internal competitiveness might hinder the success of the implementation of common research infrastructures (such as multi-user laboratories).

The literature lacks relevant studies that associate physical resources constraints to knowledge production in the developing world. It is generally understood, however, that infrastructure weaknesses lead to "low levels of scientific output and further under-development" in emerging economies (Chan and Costa, 2005, p.142). Saravia and Miranda (2004, p.612) also indicated physical infrastructure as a crucial input to science that is "generally unavailable in developing countries". At Embrapa, however, it is not the absence of physical resources, but their unequal distribution — coupled with a highly competitive internal environment — that represents a significant obstacle to a genuinely collaborative research environment.

Adair (1995, p.646) argued that the 'perception' of a resource deficiency is even more crucial than an actual deficiency: "resources may be present, but researchers will not seek them out if they believe they are not available". Following this reasoning and considering this thesis' findings, it can be said that, even where multi-user research facilities exist, they might not operate as such, if a supportive culture of collaboration is not in place. Therefore, more than merely creating common research facilities, fostering an information culture that encourages 'information-as-process' to take place and 'information-as-knowledge' to be created and shared is needed, so as to incite a more collaborative research culture.

5.4 The paradox of competition and collaboration in agricultural research

The cumulative effect of the 'macro' properties of the agricultural research system discussed in the previous sections is a continuous conflict between collaborative and competitive forces. Agricultural researchers need to engage in collaborative networks in order to satisfactorily respond to the current, complex problems presented by society. In this sense, collaboration is an epistemological demand in contemporary agricultural research. Paradoxically, managerial aspects of the agricultural research system trigger competition amongst researchers, laboratories and Research Units. Competitive behaviour arises not only over material resources, such as grants, and research facilities, but also over more symbolic resources, such as reputation and scientific priority. The paradoxical relationship between collaboration and competition can be interpreted, therefore, as a 'holistic'[59] (or 'emergent') property of the Brazilian agricultural research system, arising from the interaction and cumulative effect of all other macro-properties.

Extra-organisational competition between universities, research institutes and all sorts of organisations is often seen as salutary — even a driving force — in research (Fuchs, 1993). The effects of competition inside research organisations, over the relationships and the daily work of researchers, nonetheless, are not sufficiently explored in the literature so far.

The few existing studies addressing the effects of competition on scientific practice give reason for concern. A recent ethnographic study involving a multidisciplinary, distributed research organisation in Belgium, found that competition might hinder the progress of research projects (Duysburgh *et al.*, 2012). Anderson *et al.* (2007) perceived an increase in the levels of competition amongst U.S. scientists and concluded that pervasive competition might jeopardise the progress and integrity of

[59] In systems thinking, a holistic property is one that is not manifested in isolation by any of the parts of a system. For transcending the properties of the constitutive parts of the system, holistic properties scarcely can be unveiled by traditional analytic science and conventional scientific methods. In parallel, the parts have properties which are not manifested by the system as a whole (Skyttner, 2005).

science. The researchers interviewed by Anderson *et al.* (2007, p.437) asserted that competition impedes the open sharing of information and contributes to questionable research conduct:

> *competition contributes to strategic game-playing in science, a decline in free and open sharing of information and methods, sabotage of others' ability to use one's work, interference with peer-review processes, deformation of relationships, and careless or questionable research conduct.*

It is noticeable that the available studies seldom connect competition and collaboration — which are in fact coexisting forces in Brazilian agricultural research. Besselaar *et al.* (2012) acknowledged, however, the need for in-depth analysis of the relation between collaboration and competition in research, and its implication for research management and policy.

At Embrapa, the conflict between collaboration and competition is sensed from the level of Research Units to that of individuals. It is apparent from the moment researchers seek information to start a new activity until the moment they make their choice as to where and how to communicate research results.

The highly competitive environment unintentionally encouraged by the managerial and organisational aspects of agricultural research affects *in situ* research the most, given the nature of the knowledge produced and the more open and collaborative character of this epistemic culture. The consequence for *in vitro* research, on the other hand, is the exacerbating of the naturally more competitive culture of knowledge production. Finding the balance between competition and collaboration, therefore, is of the greatest relevance, which is in agreement with Nowotny *et al.* (2001, p.61):

> *This endeavour [the production of knowledge] demands a sophisticated balance between, on the one hand, trust and co-operation and, on the other, fierce competition.*

In governing the ways agricultural researchers relate to one another and with information — in the three connotations of Buckland (1991) — the paradox of collaboration and competition has implications for IG in research organisations. Individualism, non-sharing of information ('-as-thing' and '-as-knowledge'), and

distrustfulness were identified as socially shared patterns of behaviour that affect the information culture at the organisation under investigation. This is taken into consideration in the development of an integrative, systemically and culturally-grounded framework for effective governance of information in research organisations, which is offered in the next chapter.

5.5 Summary

This chapter has discussed the dynamics of agricultural knowledge production at Embrapa in light of the pertinent literature. It showed that the attitudes of researchers towards information are influenced by the forces that govern the processes through which financial, human and physical resources for research are acquired.

From an epistemological perspective, a more open and collaborative system of agricultural knowledge production is being required, in order to satisfactorily respond to the current, complex problems presented by society. The epistemic cultures of agricultural research — distinguished as *in situ*, *in vitro*, and *in silico* research — were shown to differ in relation to the type of knowledge produced, outcomes intended and beneficiaries served, thus responding to the pressure for collaboration in different ways. Paradoxically, these collaborative forces contrast with managerial systems that trigger high levels of internal competition among researchers, laboratories, and Research Units. The paradoxical relationship between collaborative and competitive forces was shown to have particular implications for IG at Embrapa, for it fosters an information culture that is characterised by individualism, distrustfulness, and non-sharing of information ('-as-thing' and '-as-knowledge').

Based upon a deep understanding of the machineries of agricultural knowledge production, a framework for effective governance of information was developed, which is offered in the concluding chapter, as the ultimate outcome of this study.

Chapter Six. CONCLUSIONS

We can't impose our will on a system. We can listen to what the system tells us, and discover how its properties and our values can work together to bring forth something much better than could ever be produced by our will alone.

(Meadows, 2008, pp.169–170)

6.1 Introduction

This study has identified epistemic, managerial and cultural factors with implications for the governance of information in a Brazilian agricultural research organisation. This was achieved by means of a systemic, two-level analysis of the transformative processes through which agricultural knowledge is produced out of a set of inputs.

While the 'macro-level' of analysis explored the dynamics of the wider agricultural research system in Brazil, the 'meso-level' examined the culture and practice of agricultural knowledge production at the Brazilian Agricultural Research Corporation (Embrapa). Each systemic level was regarded as embedded in the other and both levels were considered in the context of information governance. The conclusions of this two-level analysis, which meets Research Objectives 1 to 3 of this thesis (as stated in section 1.4 of the introductory chapter), are presented in sections 6.2 and 6.3 of this chapter.

Based on a deep understanding of the 'machineries of [agricultural] knowledge production' (Knorr-Cetina, 1999), an integrative, systemically and culturally-grounded framework for effective governance of information in a public research organisation was developed, which is presented in section 6.4. Recommendations of concrete actions to be taken towards more effective governance of information at Embrapa are presented in parallel, contributing to meet Research Objectives 4 and 5 of this thesis.

The chapter then shifts to reflect on the contributions of this study to current understanding (section 6.5) and appropriateness of the methodology adopted (section 6.6). Limitations of the study are then considered in section 6.7, while potential avenues for future research are set forth in section 6.8. Concluding this thesis, section 6.9 is a reflection on my own intellectual journey and disciplinary background.

6.2 Brazilian agricultural research from a macro-perspective: lessons learned in relation to information governance

This study has described and explained the dynamics of the agricultural research system in Brazil in terms of key macro-properties. Some of these properties were shown as having an epistemological nature, whereas others were related with managerial aspects of agricultural research. As to their influence on the governance of information at Embrapa, the two groups of macro-properties were found to differ widely.

Included in the first group of macro-properties, the 'increasing complexity of research problems' was demonstrated as being the impetus of change in the ways agricultural knowledge is produced in Brazil. To cope with the multifaceted problems presented by contemporary society, a more open, reflexive, and collaborative system of agricultural knowledge production is being required. This was evidenced by the fact that disciplinary, institutional, and national boundaries are becoming more and more blurred, with increased participation of societal audiences in the research process.

In terms of IG, the first implication of the scenario depicted above is a progressive diversification of the types of 'information-as-thing' (Buckland, 1991) needed by researchers. To adequately satisfy their information needs, while coping with increasingly complex problems, researchers (individually) have had to develop new skills and grow to become confident, independent information seekers, using a greater number of channels and sources of information. Another consequence of this scenario is a critical requirement for collaborative sharing of 'information-as-thing' and '-as-knowledge', necessarily accompanied by more fluid informal communication flows, both internally at Embrapa (across laboratories, departments and Research Units) and with the outside world (external peers and societal audiences).

In contrast to this emphasis on sharing, the macro-properties that relate to managerial aspects of the Brazilian agricultural research system invite individualism and competitive behaviour between departments, laboratories and researchers. From the macro-level analysis, therefore, it was discovered that collaboration — as an epistemological demand of contemporary agricultural research in Brazil — is continuously faced with competitive forces that emanate from the research funding/steering schemes and the systems of resources allocation, performance

evaluation and reward. The paradoxical relationship between collaboration and competition was then identified as a 'holistic' property of the Brazilian agricultural research system, since it arises from the interaction and cumulative effect of all other macro-properties.

This central phenomenon has a direct influence on the ways agricultural researchers relate to one another at Embrapa, instilling high levels of internal competitiveness, affecting internal communication flows and leading to low levels of synergy between individuals and departments. These competitive forces have harmful consequences for the information culture at Embrapa, as they disturb the sharing of 'information-as-thing' and '-as-knowledge'. Such an information culture has an influence on the overall information governance at Embrapa, which can be usefully explained through a political metaphor ('Feudalism' and 'Technocratic Utopianism'), as presented in the next section (6.2.1). **Table 5** summarises the identified macro-properties of agricultural research, their cumulative, systemic effect, and significance in the context of information governance.

Table 5. Macro-properties of agricultural research in relation to information governance.

Perspective	Macro-properties of agricultural research in Brazil	Cumulative effect	Implications for the governance of information
Epistemological	▪ Focus on societal impact ▪ Broadening of scope and increasing complexity of research problems ▪ Gradual intensification of cross-institutional and cross-national, multidisciplinary networking ▪ Greater participation of societal audiences and increased pressure for communication beyond scientific circles	Critical requirement for **collaboration**	▪ Diversification of the types of information needed by researchers ▪ Researchers are becoming more confident, independent information seekers, now using a greater number of sources of information and diverse channels ▪ Informal communication (internally and externally) grows as an important source of information ▪ Information services required to serve external audiences ▪ Requirement for collaborative sharing of 'information-as-thing' and '-as-knowledge'
Managerial	▪ Diversification of funding sources and competitive funding ▪ Greater emphasis on research steering and priority-setting ▪ Increasing focus on the commercialisation of knowledge ▪ Increasing pressure for accountability and research quality monitoring ▪ Strong focus on academic impact ▪ Heterogeneity in terms of physical and human resources availability	Exacerbation of internal **competition**	▪ Poor or blocked internal communication flows ▪ High levels of competition and distrustfulness in the internal environment, disfavouring 'information-as-process' ▪ Individualist information culture ▪ Low levels of synergy and cross-departmental partnerships ▪ Little convergence of information systems ▪ Fragmentation of activities towards 'information-as-thing' and '-as-knowledge'

6.2.1 A political metaphor to explain the governance of information at Embrapa

A political metaphor is useful in explaining the information governance (IG) at Embrapa. Borrowing the terms used by Davenport *et al.* (1992) to describe models of information politics in organisations, it can be concluded that, at Embrapa, information is governed under combined regimes of 'Technocratic Utopianism' and 'Feudalism'.

Embrapa's approach to IG demonstrates a strong bias towards a technological perspective, meaning that a regime of 'Technocratic Utopianism' is in force — identified by Davenport *et al.* (1992) as that in which efforts to alleviate information issues converge to the implementation of information technology 'solutions'. Davenport *et al.*'s (1992) depiction of 'Feudalism', however, is also representative of Embrapa's approach to IG. Extending Davenport's notion to include the three connotations of the term information, this political regime may be distinguished by a fragmentation of initiatives, across diverse 'realms', towards the management of 'information-as-thing' and '-as-knowledge' (Buckland, 1991). These realms develop different languages (conceptual divergence) and information systems, causing barriers to 'information-as-process' and difficulties in the access to relevant 'information-as-thing', ultimately preventing the collaborative creation and sharing of 'information-as-knowledge'. An absence of formal, organisational guidelines reinforces the *status quo*, causing uncoordinated operation in the organisation, as a whole, and consuming scarce resources.

It was concluded that the occurrence of 'Feudalism' at Embrapa is an echo of the highly competitive environment of agricultural research in Brazil. This political regime, however, is detrimental for organisations that need to operate through integrated and collaborative networks (which is the case with Embrapa), producing negative effects on research outcomes.

The framework for IG that is presented later in this chapter (section 6.4) can assist Embrapa in moving from the political models of IG that were detected ('Technocratic Utopianism' and 'Feudalism') to a more effective one, such as 'Federalism', which is characterised by coordinated operation, negotiation and consensus on the organisation's key information elements and reporting structures.

6.2.2 The uniqueness and dynamism of research systems: speaking back to Mode 2

Other important conclusions can be drawn from the macro-level analysis. First, the fact that several of the macro-properties have been observed as 'increasing' or 'intensifying' indicates that these are not static but dynamic features that at the moment are on the rise. The overall picture would certainly be different if taken a few years ago or in a few years to come, which emphasises the dynamic nature of research systems. This fact, together with the observation that some of these macro-properties are site-specific (e.g. heterogeneity in terms of resources availability, which might be inherent to a developing country context) challenges explanatory models for the recent evolution of science that fail to acknowledge the diverse cultures of knowledge production, instead adopting a unitary view of science (as with Mode 2 knowledge production and Post-normal Science, among other theorisations).

The appropriateness of Mode 2 as an explanatory framework for the recent developments in Brazilian agricultural research was examined, however, for its prominence among the conceptualisations of changing research systems available in the literature to date and, also, for appreciating the participation of other institutions (besides universities) in the production of knowledge. The conclusion of this analysis is that not all changes in the process of agricultural knowledge production at Embrapa can be explained in terms of Mode 2's imperatives. Some of the features of Mode 2, such as 'knowledge production in the context of application' and 'institutional heterogeneity' do not represent new developments in agricultural research. Other features, such as 'increased social accountability' and 'reflexivity', which could be empirically verified, occur at varying levels across the different epistemic cultures of agricultural research. 'Quality control' has intensified, but mechanisms are still restricted to the scientific community and, finally, the findings contradicted Mode 2's imperative of 'transdisciplinarity'.

It can be concluded, therefore, that agricultural research in Brazil is moving towards its own new mode of knowledge production — preferably called 'Mode n', as a form of emphasising that this is a heterogeneous, dynamic development across the different epistemic cultures and the national territory.

6.3 The epistemic cultures of agricultural research: lessons learned from the meso-level analysis

This study has revealed that, while from a macro-perspective Brazilian agricultural research might appear as a solid, cohesive knowledge domain, a meso-level analysis reveals distinct cultures of agricultural knowledge production — that is, different epistemic cultures (Knorr-Cetina, 1999). It was shown that *in situ*, *in vitro*, and *in silico* research differ not only for the experimental settings where knowledge production takes place, but for a range of other features, such as the nature of knowledge and outcomes produced, the groups of beneficiaries served, and the levels of engagement of these groups in the research process.

By being embedded in the macro-level of analysis, the three epistemic cultures are subject to the forces that govern the whole agricultural research system in Brazil. By being widely dissimilar, however, *in situ* and *in vitro* research respond differently to the conflict of collaboration and competition — a holistic property of Brazilian agricultural research with central implications for the governance of information.

In situ research is not prioritised in the competitive environment that is unintentionally encouraged by managerial and organisational aspects of agricultural research in Brazil. This is due to the more open and collaborative character of this epistemic culture, which is focused on the production and wide dissemination of pragmatic knowledge for the benefit of local farmers and agricultural systems. For *in vitro* research — which concentrates on the production of cumulative knowledge that is mostly disseminated within the scientific community, with a view to commercialisation and profit — such an environment exacerbates the naturally more competitive epistemic culture.

An important conclusion from the meso-level analysis, therefore, was the fact that *in situ* research is more conducive for collaborative information sharing (of both 'information-as-thing' and '-as-knowledge') than *in vitro* research. Nonetheless, an absence of incentives and support mechanisms make collaborative information sharing — beyond the limits of research projects and 'invisible colleges' — not usual in any of the epistemic cultures of agricultural research at Embrapa.

The levels of internal collaboration can be increased, however, by improving managerial systems so as to acknowledge the peculiarities of the different epistemic cultures of agricultural research — such as common outcomes and patterns of communication. This would, in turn, result in an improvement of the governance of information. The significance of the meso-level analysis in informing the actions that can be taken towards improving the governance of information is further developed in section 6.4.1.

6.4 Conceptualising and building the information governance framework

Exploring and developing the notion of information governance (IG) as a holistic approach to information in research organisations was the main aim of this study. An underlying assumption was that efforts to improve the IG in research organisations would not succeed if socio-cultural aspects were ignored. To circumvent that, the IG framework should be built upon an understanding of what it really meant to do agricultural research in Brazil, from both a macro- and a meso-perspective.

The relationships that were found between the macro- and meso-properties (epistemic cultures) of agricultural research and the governance of information at Embrapa have been highlighted previously, with emphasis on the pervasive and overriding tension between collaborative and competitive forces. Based on an in-depth understanding of these interrelationships, a new, holistic and culturally-grounded approach to IG was developed, starting from the following definition:

> *IG is the set of activities aimed at managing 'information-as-thing' and providing the enabling conditions for 'information-as-process' to take place and 'information-as-knowledge' to be created and shared within the organisation, in support of the research activity.*

To fully understand IG in context, some considerations are needed. First, it should be noted that, despite fostering an integrative view of information — incorporating the notions of 'information-as-thing', '-as-process', and '-as-knowledge' (Buckland, 1991) — the IG concept makes distinction as to how information is to be approached in each of these connotations.

Implicit in the IG definition is the perception of 'information-as-thing' as the only form of information that is tangible and therefore subject to management. Accordingly, no attempt is made at 'managing knowledge'. Instead, effort is put into forging the conditions that enable and stimulate 'information-as-process' to take place and 'information-as-knowledge' to be created and shared within the organisation.

The following section details the integrative framework for effective governance of information in research organisations, which represents the principal contribution of this thesis for future research and practice. Recommendations of systemically-desirable and culturally-feasible changes that can be implemented at Embrapa, as a means to improve the governance of information are presented in parallel.

6.4.1 A systemically and culturally-grounded framework for effective governance of information in research organisations

A systemically and culturally-grounded framework for effective IG in research organisations (**Figure 19**) would comprise two essential and interrelated domains. These are the 'management domain' and the 'cultural domain'.

The management domain is subdivided into a 'regulatory component' and an 'infrastructure component'. Examples of concrete actions that might be taken as part of the regulatory component are the development of policies and formal guidelines, and the definition of a common vocabulary, clear roles and responsibilities in relation to 'information-as-thing' (Buckland, 1991). This would address some of the difficulties found at Embrapa, such as the fragmentation of activities, duplication of efforts, and weakened central power in relation to 'information-as-thing'. The 'infrastructure component', on the other hand, seeks to guarantee the acquisition, organisation, preservation, and retrieval of 'information-as-thing' through a variety of services and processes (to which information technology is instrumental). At Embrapa, this would require an effort towards the development of interoperable information systems, so as to provide wide access to 'information-as-thing' across the geographically dispersed Research Units.

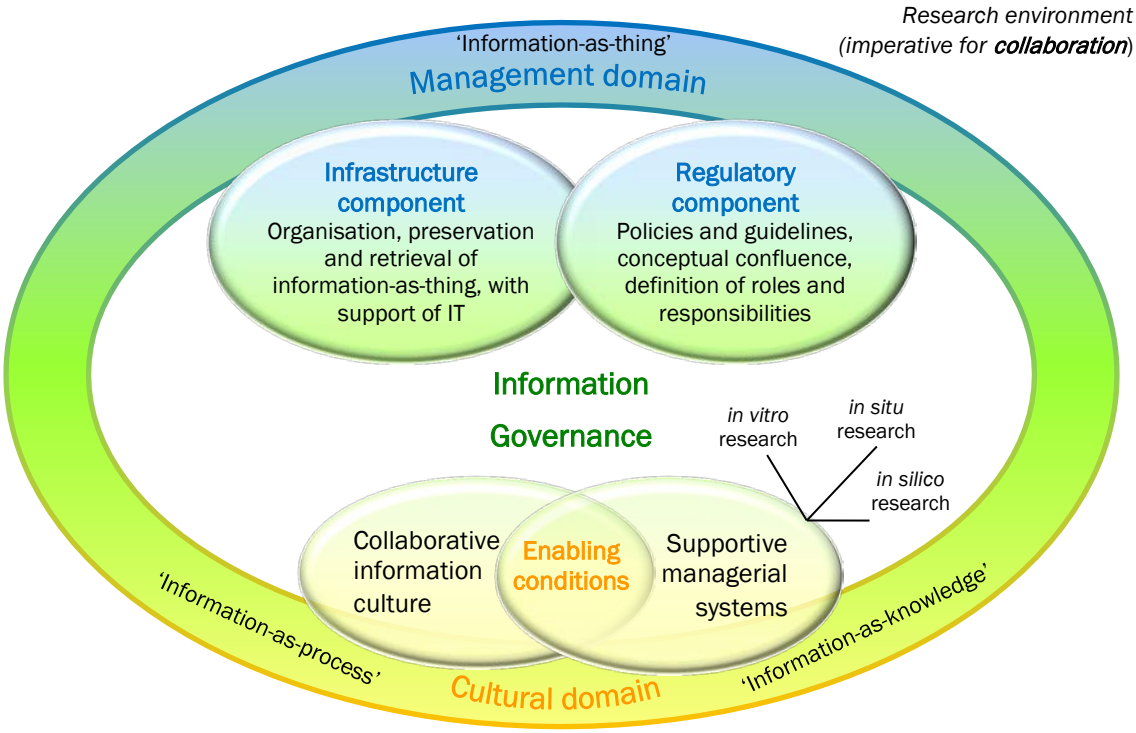


Figure 19. Framework for effective information governance in an agricultural research organisation.

Given the imperative for collaboration in contemporary agricultural research, the cultural domain of the IG framework needs to focus on setting up the conditions that enable and stimulate 'information-as-process' — the act of creating and imparting 'information-as-thing' and '-as-knowledge'. 'Enabling conditions' should include instilling an information culture that is conducive for the sharing of 'information-as-thing' and '-as-knowledge' — the argument being that every organisation has an information culture, which is a component of the broader organisational culture and which does or does not facilitate the governance of information. The following elements are indicative of the information culture in a research organisation: the levels of interaction between individuals and between those and information resources ('information-as-thing', '-as-process', and '-as-knowledge'); the effectiveness of internal communication flows; the intensity of departmental and research partnerships; and the general internal atmosphere.

The emphasis on cultural issues, in the IG framework, is a way of acknowledging that interactions between researchers (and between these and information) are determined by their individual goals, challenges, and research interests. In the case study, for instance, researchers' pursuit of recognition and reward, as well as all the processes through which the necessary inputs to agricultural research are obtained,

were shown to instil a non-collaborative information culture. Developing an information culture that is conducive for 'information-as-process' at Embrapa, therefore, would most certainly require a change in the performance evaluation and reward system.

This is where the different cultures of agricultural knowledge production play a crucial role. The performance evaluation and reward system should reflect the fact that *in situ*, *in vitro*, and *in silico* research produce different types of outcomes in equally different time frames. While the productivity of *in vitro* and *in silico* researchers can be indirectly assessed in terms of scientific articles published, the same criterion does not apply to *in situ* research, where the main channels for communication of results are conferences, events and publications directed to farmers and rural technicians.

It is argued that modifying the merit and reward system in accordance with the different epistemic cultures of agricultural research would reduce the internal levels of competition among researchers, favouring a more collaborative information culture and positively impacting on the governance of information. Other corporate systems that would need improvement at the organisation investigated, to support a more collaborative information culture, are: Research Units' performance assessment; research monitoring control; and financial, physical and human resources allocation (so as to minimise discrepancies across Research Units).

Changing the information culture of an organisation, however — as any cultural change — cannot be accomplished with ease but requires long-term action. The point that is being made here, however, is that appropriate managerial systems might induce a change in the motivation of researchers, bringing about a more collaborative information culture.

Improving the governance of information is closely related to forging a more collaborative environment of research. For this reason, collaborative efforts between individuals, laboratories, and Research Units ought to be recognised and rewarded by managerial systems — not only in support of a more collaborative information culture but for the advancement of agricultural knowledge.

The IG framework proposed in this thesis, therefore, is a managerially-useful construct, in assisting the identification of systemically-desirable and culturally-feasible changes that can be implemented, so as to improve the governance of information in research

organisations (which, based on this research findings, would facilitate the achievement of research outcomes). Finally, IG is to be seen as one element — a very important one — of the general governance program in the organisation. As well as with people, finances and physical resources, weaknesses in the governance of information might affect the success and sustainability of research organisations in the age of the Information Society.

6.5 Contributions of this study

The uniqueness and main contributions of this study to current understanding are highlighted in the next subsections.

6.5.1 Managing 'information-as-thing' and enabling 'information-as-process'

This thesis has made an important contribution for the practice of IKM, by reconciling and offering a single, managerially-useful construct for research organisations to cope with information in the three connotations distinguished by Buckland (1991) — 'information-as-thing', '-as-process', and '-as-knowledge'. Although considerably complementary and mutually dependent, traditional management approaches in organisations tend to treat 'information' and 'knowledge' issues separately, causing confusion, duplication of efforts, and waste of resources.

Analogously, having proposed a framework that aims at the management of 'information-as-thing' while facilitating 'information-as-process' to take place and 'information-as-knowledge' to be created and shared, this study also fills a gap in the current literature in IKM. Although some of the conceptual elements of the proposed IG framework might not be new, its contribution lies in harnessing and ensuring highly connected interaction between information and knowledge management, situating information issues in the context of the research organisation and in relation to other managerial systems. Getting to this result, however, was only possible in virtue of a holistic and systemic way of thinking.

6.5.2 The unit and scale of analysis

Having employed a systemic approach to understand the macro-dynamics of agricultural research in Brazil and the epistemic cultures (Knorr-Cetina, 1999) of

researchers from Embrapa, this study yielded findings that aligned on two different levels of granularity — the 'macro-' and the 'meso-level'. A micro-level of analysis would focus on the individual actions of researchers, which was not a purpose of this study, due to an understanding that "once a social system is in place, individuals become replaceable to some extent; their roles can be enacted by different persons" (Bunge, 2000, pp.149-150).

It is worth highlighting, however, that the terms 'macro', 'meso', and 'micro' are relative, forming a continuum in such a way that, what is macro from one's perspective may be micro from another's (Eulau, 1986, p.90). In other words, what is macro, what is micro and what is in-between in a social study is a choice of the researcher. In the present study, the meso-level fitted between the micro-level context of the participants' individual perceptions and the macro-level context of the larger system of agricultural knowledge production. Embedded within the macro-level, the meso-level of analysis allowed the identification of different units of organisation in agricultural research; different epistemic cultures.

One of the sources of uniqueness of this study is that it represents an insightful approach in reconciling the understanding of the functioning of large research systems with knowledge production at local settings. By looking at the meso-level, the 'disunified' nature of agricultural knowledge production could be observed, revealing variations that otherwise would not have been perceived. For instance, whilst 'focus on societal impact' stood as a macro-property of the agricultural research system, the level of engagement of society in the research process was found to vary across epistemic cultures.

Correlating between the macro- and the meso-level allowed appreciation of cultural, epistemic, and managerial aspects with implications for the governance of information. The pervasive tension between collaborative and competitive forces, for example, which was identified as a holistic property of agricultural research, was found to undermine effective IG, inciting 'feudal' actions (Buckland, 1991). Such a regime was proven to affect *in situ* research the most, due to the naturally more open and collaborative character of this epistemic culture. Correlations like this informed the development of the IG framework, which represents an important contribution to current understanding in the Information and Knowledge Management field.

While approaching the epistemic disunity of contemporary agricultural research in Brazil, however, the focus of this study was on the identification of forces that could affect the governance of information in a research organisation. The level of understanding of these cultures was as deep as necessary to verify relationships between key macro- and meso-properties of agricultural research and the governance of information at Embrapa. Unravelling the complexities of the different epistemic cultures was not the purpose of this research nor was it necessary to accomplish the research aim and objectives. Digging deeper into each epistemic culture is one of the potential areas for future work (section 6.8).

6.5.3 The context: beyond universities and the developed world

As discussed in the literature review, the theorisations of changing research systems commonly take a country-perspective, concentrating on the context of the highly developed nations in the world and on the central role of universities as the locus of scientific knowledge production. The Enterprise University (Marginson and Considine, 2000), for instance, was aimed at Australian universities, while Academic Capitalism (Slaughter and Leslie, 1997) examined developments in Australia, Canada, United Kingdom, and United States of America.

By investigating the dynamics of agricultural research in a developing country, therefore, this study contributed to fill an important lacuna in the literature. Especially in relation to contemporary agricultural research in Brazil, the literature is scarce. By inquiring on research from the perspective of a public institute, as the locus of scientific knowledge production, this study makes a further contribution to the current knowledge.

6.5.4 Differentiating IG from Davenport's information politics framework

The IG framework presented in this thesis builds upon the notion of information politics of Davenport *et al.* (1992). Borrowing their political metaphor, the alternate models of IG at Embrapa were depicted as regimes of 'Feudalism' and 'Technocratic Utopianism', as previously discussed in section 6.2.1. Despite providing useful insights into the ways researchers, departments, and the organisation as a whole cope with information, however, there are significant differences between Davenport's and this research's approach to IG.

In the first place, while the IG framework presented in this thesis considers all three connotations of the word information, the approach of Davenport *et al.* (1992) is restricted to the realm of 'information-as-thing' (Buckland, 1991). In this regard, there is considerable similarity between Davenport's IG approach and what could be called a well-built 'information management' strategy. As a matter of fact, the four dimensions along which Davenport (1992) assessed information politics models in organisations — commonality of vocabulary, access to important information, quality of information, and information management — are all equally pertinent to the notion of information management. It is also worth noting that a cultural dimension was not among the indicators according to which Davenport *et al.* (1992) assessed the models of information politics in organisations. The authors did acknowledge the importance of cultural aspects for the establishment of the several political regimes, though, and later, in the seminal book that introduced the notion of 'information ecology', Davenport (1997) emphasised the relevance of approaching the entire information environment, including cultural and political issues, behaviour and work processes, and technological aspects.

In line with that, the IG framework that is proposed in this thesis embraces managerial and cultural aspects as core components, therefore equally determinant of its success of failure. The main difference between this study's approach to IG and Davenport's (1997) 'information ecology' model, therefore, is that it offers a single, managerially-useful construct for organisations to cope with 'information-as-thing', '-as-process', and '-as-knowledge' (Buckland, 1991) in a highly interconnected way.

6.6 Appropriateness of the methodology: embracing complexity through systemic thinking

Does this study belong to the domain of Information Science or Science and Technology Studies? This research cannot be easily categorised as belonging to either one or the other: it is situated at their intersection. It is, in fact, an example of interdisciplinary research effort.

The uniqueness in a systemic, holistic research approach is that a single researcher is making every effort to visualise a problem from different perspectives. More important

than the disciplinary area to which this research would fit, therefore, is the focus of research, which determined the methodological possibilities.

In order to inquire as to the influence of the wider context of agricultural research over the governance of information in a Brazilian research organisation, embracing a holistic, systemic way of thinking was imperative. Here, as in Skyttner (2005, p.38), holism is "an attempt to bring together fragmentary research findings in a comprehensive view on man, nature, and society". Instead of aiming at the micro constituents of the system, therefore, attention was paid to the properties that might be applicable to a collection of parts of the system, in order to explain how things are "compounded and work together in integrated wholes" (Skyttner, 2005, p.V).

In this thesis, systems thinking provided the tools to avoid reductionism while tackling the complexity of the real world, by expanding the focus of observation and embracing complexity from the beginning of the research process. As Skyttner (2005, p.34) summarised: "analysis gives description and knowledge; systems thinking gives explanation and understanding".

A flexible use of the Soft Systems Methodology (SSM) of Checkland (1981) helped unravel the complexities of IG at Embrapa, allowing in-depth learning and appreciation of the problem situation within its contemporary real world context. By looking at agricultural research as a system and focusing on the process through which a set of inputs is transformed into knowledge, epistemic, managerial, and cultural aspects came to light, which were found to have crucial implications for the governance of information at Embrapa.

It is worth emphasising, however, that the present conception of research as an input-output system differs from that traditionally held for the purpose of research evaluation, which focuses on science productivity assessments, performed by means of bibliometric analyses and output-input ratio evaluations. Here, instead of quantifying inputs and outputs of agricultural science, the focus was on the processes happening in-between: those taking place inside the 'black box' that is the scientific endeavour, where the machineries of agricultural knowledge production operate (Knorr-Cetina, 1999).

6.7 Limitations of this research

The context considered in this investigation was a specific one: that of a research organisation based in a developing country. This fact, *per se*, limits the generalisation of results for other settings — such as those of universities or other research institutes that share little resemblance to Embrapa and Brazil.

The functioning of research systems might vary considerably across different nations and scientific fields. Similarly, research organisations can take many forms — from the simplest structures to large, geographically dispersed corporations (such as Embrapa). Besides, both research systems and research organisations are dynamic entities.

From a holistic perspective, therefore, instead of forming generalisations about the ensemble of research systems and research organisations, based on observations which apply to just a few, a more accurate understanding comes from in-depth investigation of each context. In this sense, the present study stands like a snapshot that is analysed in detail and provides useful insight into the complexities of contemporary research systems and the issue of IG in research organisations.

6.8 Avenues for future research

There are potential avenues for future research, which can be framed as follows:

a. Employing the framework in other research organisations

There is a particular need to explore the IG framework in other research organisations. In order to do so, a set of criteria needs to be developed, from the framework that was proposed, so that it could be tested in other research organisations — from developing countries or not. Both analyses could yield interesting results in terms of the transferability of the framework for other settings.

b. Investigating the suitability of the framework for organisations in other sectors

The IG framework produced in this study was built to suit research organisations. However, its principles could be adjusted for and verified in organisations in other business sectors.

c. Defining and implementing systemically-desirable and culturally-feasible changes

Moving on with the Soft Systems Methodology (Checkland, 1999), there is promising work to be done at Embrapa. This should begin with a wide debate — horizontally and vertically, across central divisions and research departments — of the framework for IG, in order to define the systemically-desirable and culturally-feasible changes that can be implemented. Conflicting interests would need to be accommodated, so that action could be taken to bring about improvement in the problem situation. This would demonstrate the validity of the model, its constructs and measures.

d. Further investigating the different epistemic cultures of agricultural research

This study gave first hand evidence of the coexistence of different epistemic cultures in agricultural research. Unravelling the complexities and the dynamics of each of these cultures would represent a significant contribution to current understanding in Science and Technology Studies.

e. Developing longitudinal studies

Further insights into the dynamics of the agricultural research system in Brazil could be achieved through longitudinal studies that look at each of the developments described in this thesis at different (future) points in time. This would allow continuous learning and updating of the IG framework.

6.9 Reflections on my intellectual journey and disciplinary background

My background is from the domain of the Biological Sciences, in which I achieved my Bachelor and Master's degree. Working as a researcher in Molecular Methods at the Brazilian Agricultural Research Corporation was the shortest part of my professional life, though. In most of my time at Embrapa, I worked as a co-editor at a scientific journal and subsequently, as an information manager in a Service Unit that is responsible for the organisation and dissemination of the information generated by research to its varied audiences.

An inclination towards systemic thinking came as a consequence of my mixed educational and professional experience, doing a bit of everything in the organisation.

This PhD research presented me, however, with a number of challenges; my academic tradition and scientific dogmas were confronted throughout the process, but learning was incredible, corroborating the opinion of Skyttner (2005):

> *To engage oneself in systems science is therefore a highly cross-scientific occupation. The student will come in contact with the many different academic disciplines: philosophy, sociology, physics, biology, etc. The consequent possibility of all-round education is something particularly needed in our over-specialized society. (Skyttner, 2005, p.4)*

Besides, realistically speaking, I was not an outsider to the problem under investigation. This impeded the adoption of methodologies that require absolute detachment of the researcher from the object of investigation. Although it is the perspective of the participants that was put forward into the data analysis, my world-view, personal experiences, and accumulated knowledge certainly influenced the reading that was made, from the whole situation under analysis. This fact is not seen as a compromise, though. Quite the reverse, from the combination of my natural stance as a biologist, to the continuous learning into the arenas of both Information Science, and Studies of Science and Technology, originates all the richness of the perspective presented.

The universe is a Systems-Hierarchy. It has evolved in a cumulative manner, each higher step in this hierarchy, after the first, consisting of lower step components plus a new entity which has emerged out of the hierarchy, mutually modified. The world is therefore at the same time 'richly strange and deeply simple' [...]

When you observe the cumulative edifice from below you are amazed to see that the structure of all the higher rings is potential and implicit in the forms and laws of the lower ones. And conversely, when you observe the universe from its highest rings you see that they collapse into huge numbers of their lower ring components.

(Haskell, 1972, p.21)

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Appendices

Appendix I. List of interviewees

No.	Pseudonym[60]	Gender	Academic background	Specialist area of interest	Years*
			Researchers		
1	Christian	M	Agricultural Engineering	Plant pathology (PP)[61]	38
2	Franklin	M	Agricultural Engineering	PP/molecular plant-pathogen interactions	2
3	Frederick	M	Agricultural Engineering	PP/computational modeling	11
4	Maryann	F	Biological Sciences	Soil microbiology[62]	9
5	Alan	M	Agricultural Engineering	PP/molecular plant-pathogen interactions	10
6	Michael	M	Agricultural Engineering	PP/biological control	23
7	Alicia	F	Chemistry	PP/mechanisms of tolerance to stress	10
8	Adele	F	Agricultural Engineering	Soil and plant nutrition[63]	7
9	Ashleigh	F	Agricultural Engineering	Soil and plant nutrition	32
10	Israel	M	Agricultural Engineering	Soil and plant nutrition	4
11	Colton	M	Agricultural Engineering	Molecular biology[64]	15
12	Lindsay	F	Agricultural Engineering	Molecular biology	10
13	Margaret	F	Agricultural Engineering	Molecular biology	7
14	Corey	M	Agricultural Engineering	Plant genetics[65]	30
15	Jacob	M	Agricultural Engineering	Plant genetics	33
16	Tiffany	F	Food Engineering	Plant genetics	5
17	Luke	M	Agricultural Engineering	Genomics/proteomics[66]	31
18	Madeline	F	Biological Sciences	Genomics/proteomics	13
19	Angelica	F	Agricultural Engineering	Natural resources[67]	14
20	Eric	M	Biological Sciences	Natural resources	23
21	Merton	M	Electronic Engineering	Information systems[68]	18
			Information and knowledge managers		
22	Thomas	M	Computer Science	Information management	7
23	Robert	M	Computer Science	Knowledge management	22
24	Vanessa	F	Library/Information Science	Information management	10

*Years of work at Embrapa.

[60] In the interests of anonymity, pseudonyms have been used to identify individual interviewees, in accordance with the terms of confidentiality of the 'Informed Consent Form' (**Appendix IV**).

[61] 'Plant pathology', also named phytopathology, is the study of plant diseases caused by pathogens (infectious organisms) and environmental conditions (physiological factors). Specific interests in plant pathology may include the study of plant-pathogen interactions, computational modelling, biological control, mechanisms of tolerance to stress, among many others.

[62] 'Soil microbiology' studies organisms in soil, their functions, and how they affect soil properties.

[63] 'Soil and plant nutrition' is the study of the properties of the soil, as a natural resource, and the chemical elements that are necessary for plant growth.

[64] 'Molecular biology' is the branch of biology that deals with the molecular basis of biological activity. This field overlaps with other areas of biology and chemistry, particularly genetics and biochemistry.

[65] 'Plant genetics' is the study of genetics in botany. Typical work is done with genes in order to isolate and then develop certain plant traits. Once a certain trait (e.g. fruit sweetness or tolerance to cold) is found, a plant geneticist works to ensure that future plant generations possess the desired traits.

[66] 'Genomics' is a branch of biotechnology concerned with applying the genetics and molecular biology techniques to the genetic mapping of sets of genes or the complete genomes of selected organisms. 'Proteomics' is a branch of biotechnology concerned with the structure, function, and interactions of the proteins produced by the genes of a particular cell, tissue, or organism.

[67] 'Natural resources' research is the study of nature, biodiversity, geo-diversity, and ecosystems.

[68] Research in 'information systems' (as related to agricultural science) is the study of information technology systems and appreciation of how these can be used both operationally and strategically in support of agriculture.

Appendix II. Researchers consulted in the validation stage

No.	Pseudonym[69]	Gender	Academic background	Specialist area of interest	Years*
1	Andrew	M	Agricultural Engineering	Plant genetics	36
2	George	M	Agricultural Engineering	Plant genetics	5
3	Matthew	M	Agricultural Engineering	Plant genetics	23
4	Megan	F	Agricultural Engineering	Post-harvester physiology[70]	17
5	Rosie	F	Agricultural Engineering	Soil and plant nutrition	10

*Years of work at Embrapa.

[69] In the interests of anonymity, pseudonyms have been used to identify individual interviewees, in accordance with the terms of confidentiality of the 'Informed Consent Form' (**Appendix IV**).

[70] 'Post-harvest physiology' is concerned with the study of the processes occurring immediately following harvest, such as cooling, cleaning, sorting and packing so as to improve the quality of crop and food production.

Appendix III. Thematic interview guide

Date: / / Place: Embrapa's Unit:
Interviewee: Admitted at Embrapa: / /
Position: Main field of research:
Education:

Academic background and career at Embrapa

Before going into the main subject of this interview, I would like to get some information about your academic history and your career at Embrapa.

1. Tell me about your academic history. What is your main background? From which universities did you get your degree(s)?
2. In which Research Unit(s) have you been working since admitted to Embrapa?

Research culture and practices

Now, we are going to talk about the research culture in your field. Also, we are going to discuss about the inputs and the outputs your research is supposed to generate.

3. How could you describe and characterise your research area? What topics are you mostly interested in?
4. What stage of research are you in at the moment? (What exactly are you doing now? e.g. one study completed and written, data collected for a second, writing a research proposal, a paper…)
5. Who defines and how are research priorities defined in your area?
6. How and where do you get the funds and resources for developing your research? How competitive is this process?
7. How is the quality of research assessed at Embrapa? Besides the organisation, itself, who else show an interest in the quality of research that is being done? Tell me about it.
8. Are there external collaborators in your research? Which organisations/universities/laboratories or formal/informal collaborators are involved in your research? Which scientific disciplines do they represent?
9. How do you exchange ideas and communicate with your research peers? What technologies do you use to support communication and collaboration in your research?
10. Tell me about the laboratory you work at. Who rules the laboratory and how is it organised in terms of project's leadership and collaboration?
11. What characteristics define a fully developed scientific researcher in your field? Would it be correct to say that 'owning a laboratory' is a common desire of researchers in your field?
12. If yes, does the laboratory leader continue to do bench work? Is the laboratory leader more oriented toward the society than the remainder of the researchers? (e.g. disseminating the work that has been done in the laboratory to the outside

world (individual researchers, laboratories, or institutions), building networks, obtaining special materials, information on unpublished and ongoing research projects, etc.)

13. Tell me about time management in a regular day of work. How much of your time is dedicated to science-related activities, compared to other activities? With which other activities do you get involved with?

- Inputs to research -

14. What kind of inputs do you usually need in order to develop your research? (e.g. information, data)
15. Do you have access to all types of information you need to access? Which specific services/sources do you use for getting the information you need (online or physically)? Are those services/sources useful? Why? (Consider a recent real task in your research practice, like writing a research proposal, a paper, conducting experiments, etc.)

- Research outputs and outcomes -

16. How do you store and retrieve information/data generated by your own research? Could you describe it?
17. Who has access to this? Are those information/data made available to other researchers, inside and outside the organisation? (data and information sharing)
18. Are there local guidelines and policies regarding information in your Research Unit? Tell me more about this.
19. What outcomes is your research potentially producing? Is there an intention to patent and commercialise any of them? (e.g. new products, software, techniques or services)
20. In doing your research, do you communicate and relate directly with farmers or any organised groups of the society? In which stages of the research and how?
21. What kinds of data/information/knowledge does your research produce or is capable of producing? Through which mechanisms do you transfer the knowledge your research generates to the interested groups?
22. Do you take part in information dissemination and science popularisation activities promoted by the organisation or of your own initiative? Briefly describe them.
23. How do you communicate research results to the scientific and professional community? (papers, conferences, workshops, seminars, email, blogs, etc.)
24. In which scientific journals do you preferably publish? What factors make you prefer those over any other? (printed or electronic, Open Access, …)
25. What motivates you to publish? Do you feel any kind of pressure to disseminate research results through scientific publications? From whom?
26. Are there internal peer-review mechanisms before submitting a paper/research project externally? Is it compulsory?
27. What defines the authorship for a journal paper in your research area? (Authorship conventions)

Concluding question

28. Besides what we have already discussed, is there something regarding the research practices in your area that you would like to highlight?

Appendix IV. Informed Consent Form

Loughborough University

Towards a model for information governance in developing countries' research organisations

INFORMED CONSENT FORM
(to be completed after Participant Information Sheet has been read)

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Advisory Committee.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence and will be kept anonymous and confidential to the researchers unless (under the statutory obligations of the agencies which the researchers are working with), it is judged that confidentiality will have to be breached for the safety of the participant or others.

I agree to participate in this study.

Your name _____

Your signature _____

Signature of investigator Patricia Rocha Bello Bertin _____

Date / /2011

Appendix V. Final code book

Main themes, sub-themes and codes
Depicting agricultural research
Historical overview
Focus on societal impact
Outcomes of research
Beneficiaries of research
Conflict between small farming and agribusiness
Weakening of the rural extension system
Research actors
Changing profile of researchers
Time constraints
Different sites of experimentation
Field-based research
Computer-based research
Laboratory-based research
Types of knowledge produced
Pragmatic knowledge
Cumulative knowledge
Collaborative aspects of agricultural research
Increasing complexity of challenges
Intensification of network research
The research project as unit of collaboration
Intensification of cross-institutional research
Internationalisation of research
Types of international collaborations
Growth of multidisciplinarity
Increased reflexivity in research
Triggers for competition in the agricultural research system
Diversification of funding sources
Relationship with industry
Intensified competition for financial resources
Emphasis on the commercialisation of knowledge
Research steering and priority-setting
Research foresight studies
Government requests
Market research and environmental scanning
Research agenda setting at the Research Unit
Focus on research accountability and quality monitoring
Research Units and employees' merit and reward system
Quality control of research proposals
Quality control of projects' execution
Quality control in the lab
Resources constraints
Human resources constraints
Physical resources and infrastructure constraints
Relationship with the external environment and communication
Relationship with the general public
Forms of communication with non-scientific audiences
Use of Information and Communication Technologies
Relationship with farmers
Participatory research
Relationship with research peers (Scientific communication)
Pressure to publish
Types of scientific output
Internal peer-review process
Patterns and authorship conventions
Scientific journal preferences

Data, information and knowledge management
Policies and guidelines
Focus on Information Technology
Fragmentation of initiatives towards data, information, and knowledge management
Data management practices and policies
Sharing and retaining knowledge
Growing role of internal communication flows
Information as a resource
Information needs of a scientific nature
Information needs of a non-scientific nature
Attitudes towards information sharing
Information seeking
Information sources, infrastructure and systems