

**Academic ‘Boundaries’ in the Context of the UK Impact Agenda: A Study of ‘Power’ and ‘Control’ in Academic STEMM Research**

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Sadly, the world is not fair.

Dedicated to Dad, wish you were here.

# Abstract

The ‘impact agenda’ for academic research denotes a set of policies which encourage and incentivise academic institutions and researchers to shift focus towards more societally and economically ‘relevant’ problems. This reflects how important an institution academia has become to addressing social, economic and global challenges. However, the impact agenda is perceived by some to represent a challenge to academia’s autonomy and value. This has provoked analytical and normative debate about the extent to which ‘academic boundaries’ are being/should be loosened, weakened or re-shaped to be more responsive to non-academic objectives and interests.

My study brings empirical evidence to bear on these debates. Drawing on sociologist Basil Bernstein, I use the ‘boundary’ metaphor as a lens through which to analyse the ‘power’ and ‘control’ over academic research. The sample is 19 bodies of research from ten departments across nine UK universities, covering a range of institutional contexts and a range of science, technology, engineering, mathematics and medicine (STEMM) disciplines. The analysis, based on 345 documentary sources supplemented by 10 interviews with key academics, focuses on the interaction between academic and non-academic ‘power’ and ‘control’ over research knowledge, and considers the implications for ‘academic boundaries’.

The analysis finds greater evidence of academic boundaries being maintained and reproduced than of their being weakened, and that this is largely because the non-academic ‘impact’ of academic research contributes to the perceived legitimacy of, and therefore strength of, academic ‘boundaries’. However, the findings also demonstrate that ‘power’ and ‘control’ over academic research is unevenly distributed, both within and beyond academic ‘boundaries’, so that certain types of university, discipline, and non-academic actor exhibit greater ‘power’ and ‘control’ than others, such that there remains cause to be concerned about the future integrityof academic boundaries, and for academic researchers to resist and take ownership over the impact agenda.

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# Glossary

**AHSS** (Arts, Humanities, and Social Sciences)

**AIG** (Astronomy Instrumentation Group): AIG is a research group responsible for the research sampled from Cardiff University.

**ARG** (Astronomy Research Group): ARG is a research group, closely related to AIG, responsible for the research sampled from Cardiff University.

**BoR** (Body of Research): This is the unit of analysis adopted in my main analytical procedures.

**BPS** (British Psychological Society)

**CEMaSS** (Centre for Environmental and Marine Sciences and Services): CEMaSS is a research group at Edinburgh Napier University responsible for research sampled in my study.

**CenTACat** (Centre for Theory and Application of Catalysis): CenTACat is a research group at Queen’s University Belfast responsible for research sampled in my study.

**CERI** (Centre for Educational Research and Innovation): CERI is a centre of the Organisation for Economic Co-operation and Development.

**CHMI** (Centre for Healthcare Modelling and Informatics): CHMI is a research centre at the University of Portsmouth responsible for research sampled in my study.

**DABRG** (Drugs and Addictive Behaviour Research Group): is a research group at the University of East London responsible for research sampled in my study.

**DMSM** (Department for Materials Science and Metallurgy): DMSM is a department at the University of Cambridge responsible for research sampled in my study.

**ENU** (Edinburgh Napier University): Edinburgh Napier University is one of the nine institutions whose research is sampled for study in this thesis. In the text, I use the abbreviated form ‘ENU’.

**EPSRC** (Engineering and Physical Science Research Council): EPSRC is a UK research funding council responsible for funding some of the research sampled.

**ESA** (European Space Agency): The ESA is an intergovernmental organisation responsible for funding the research sampled from Cardiff University.

**EWS** (Early Warning System or Early Warning Score): An EWS refers to a system for analysing the vital signs of hospital in-patients in order to provide a score whose value is an indicator for the risk of the given patient suffering a significant deterioration in their medical condition. EWS can also refer to the score, as well as to the system.

**FSDL** (Full Scale Dynamics Limited): FSDL is a spin-out company associated with engineering research sampled from the University of Sheffield.

**FSNI** (Forensic Science Northern Ireland): FSNI is an agency of the Northern Ireland government. FSNI were collaborators in and beneficiaries of research sampled from Queen’s University Belfast.

**GWSDAT** (Groundwater Spatiotemporal Data Analysis Tool): GWSDAT is a piece of software developed associated with the impact and underpinning mathematical (statistical) research sampled from the University of Glasgow.

**HEFCE** (Higher Education Funding Council for England): A defunct body responsible, among other things, for overseeing the REF. This responsibility now belongs to Research England, which is itself under the umbrella body UK Research & Innovation.

**HESA** (Higher Education Statistics Agency): HESA collects official higher education statistics for the UK.

**ICMS** (Institute of Cardiovascular & Medical Sciences): The ICMS is responsible for research sampled from the University of Glasgow.

**IMMRC** (Innovative Molecular Materials Research Centre): IMMRC is a research centre responsible for research sampled from Queen’s University Belfast.

**Impact** (including ‘Impact agenda’ and ‘Impact Case Study’): In the context of the Research Excellence Framework (REF – see entry in Glossary), ‘Impact’ is defined as “an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia”. The ‘impact agenda’ refers to the policy discourse and debates that have underpinned and led to the implementation of specific impact policies and practices, such as its introduction as an element of assessment in the REF.

**Innovate UK**: Innovate UK is the operating name of the Technology Strategy Board (TSB – see entry in Glossary). It is responsible for funding Knowledge Transfer Partnerships (KTP – see entry in Glossary) which were found to play important roles in research and impact sampled from the University of Portsmouth and the University of Cambridge.

**KMFRI** (Kenya Marine and Fisheries Research Institute): KMFRI is an official research institute. KMFRI were collaborators in research sampled from Edinburgh Napier University.

**KTP** (Knowledge Transfer Partnership): KTPs are public grants used to fund a Knowledge Transfer ‘Associate’ who brings academic skills and support into a project in a non-academic organisation. The main sponsor is Innovate UK.

**MBE** (Member of the Most Excellent Order of the British Empire)

**MCG** (Materials Chemistry Group): MCG are responsible for research sampled from the University of Cambridge.

**MoD** (Ministry of Defence): The UK MoD were collaborators on research sampled from the University of Cambridge.

**NCUB** (National Centre for Universities and Business): NCUB is a non-governmental organisation aiming to support mutual benefits through interaction between UK universities and UK businesses.

**NERC** (Natural Environment Research Council): NERC is one of the seven UK research councils. NERC is responsible for funding several bodies of research sampled in this study.

**NIDA** (National Institute for Drug Abuse): NIDA is a United States government institute which was responsible for funding sampled research at the University of East London.

**PODDS** (‘Prediction and management Of Discolouration in Distribution Systems’): PODDS is the name of the long-term project which underpinned sampled engineering research and impact from the University of Sheffield.

**POSSUM** (Physiological and Operative Severity Score for the enUmeration of Morbidity and mortality): POSSUM refers to an audit system used to measure and compare rates of morbidity and mortality in different hospitals. It is relevant to health research sampled from the University of Portsmouth.

**QMCI** (Queen Mary College Instruments): QMCI is a spin-out originally based at Queen Mary College, London. QMCI kept its brand name even after it was relocated to Cardiff University along with its key individuals. It is associated with instrumentation research and impact sampled from Cardiff University.

**QR funding** (Quality-related Research funding): QR funding refers to block research funding distributed to universities, where funding allocation is based on performance in some system of measuring research ‘quality’, such as the REF.

**QUB** (Queen’s University Belfast): Queen’s University Belfast is one of the nine institutions whose research is sampled for study in this thesis. In the text, I use the abbreviated form ‘QUB’.

**QUILL** (Queen’s University Ionic Liquids Laboratory): QUILL is a university-industry consortium associated with research and impact sampled from Queen’s University Belfast.

**RAE** (Research Assessment Exercise): The RAE was the precursor to the Research Excellence Framework (REF – see entry in Glossary). It was last conducted in 2008 and was followed by the first REF in 2014.

**RCP** (Royal College of Physicians)

**RCUK** (Research Councils UK): RCUK was an overarching body which incorporated all seven UK research councils. These are now incorporated under the larger overarching body, UK Research & Innovation.

**REF** (Research Excellence Framework): The REF is the UK’s QR funding allocation mechanism. It assesses research at UK universities according to the quality of their outputs, research environment, and non-academic impact resulting from research.

**Research England**: A non-governmental body under the umbrella organisation UK Research & Innovation. Research England took over some of the functions of HEFCE, including oversight of the REF.

**SERG** (Systems Engineering Research Group): SERG is a research group responsible for research sampled from the University of Portsmouth.

**SMRU** (Sea Mammals Research Unit): SMRU is a research unit responsible for research sampled from St Andrews University.

**SPIRE** (Spectral and Photometric Imaging Receiver): SPIRE was the name of an instrument attached to a satellite launched by the ESA.

**STEMM** (Science, Technology, Engineering, Mathematics and Medicine): Scientific disciplines (or subjects) are often grouped together in the acronym STEM. Medicine is sometimes also included to create STEMM. My empirical focus is on research based in STEMM disciplines.

**SUM network** (Substance Use and Misuse): The SUM network is associated with research and impact sampled from the University of East London.

**Third Mission**: The third mission denotes a mission of universities to ensure their activities and outputs contribute to the economy and wider society. This is distinct from its first two missions, teaching and research.

**TSB** (Technology Strategy Board): TSB is the official innovation agency of the UK. It is under the umbrella organisation UK Research & Innovation. TSB’s operating name is Innovate UK. It is responsible for funding Knowledge Transfer Partnerships which were found to play important roles in research and impact sampled from the University of Portsmouth and the University of Cambridge.

**TTO** (Technology Transfer Office): ‘Technology transfer’ is the process by which technology developed in the context of academic research is ‘transferred’ to contexts of application or directly marketed. Some universities have their own Technology Transfer Offices to assist with this market process, for example in the creation of spin-out companies or application and licensing of patented technologies.

**UEL** (University of East London): The University of East London is one of the nine institutions whose research is sampled for study in this thesis. In the text, I use the abbreviated form ‘UEL’.

**UKRI** (UK Research & Innovation): UKRI is an official umbrella organisation designed to increase the strategic co-ordination of nine relatively distinct bodies related to research and innovation in the UK: Research England, TSB (Innovate UK) and the seven research councils.

**UoA** (Unit of Assessment): UoAs are the units at which UK university’s research is assessed within the REF (see entry in Glossary). In REF2014, there were 36 UoAs, broken down into four Main Panels, labelled A, B, C and D. STEMM disciplines are covered by UoAs 1-15, which fall under Main Panels A and B. I sample BoRs (see entry in Glossary) from ten UoAs.

**VES** (Vibration Engineering Section): VES is a research unit responsible for research sampled from the University of Sheffield.

**WEG** (Water Engineering Group): WEG is a research group responsible for engineering research sampled from the University of Sheffield.

**WOSCOPS** (West of Scotland Coronary Prevention Study): WOSCOPS is the name of a long-term research project spanning over two decades. It has been sampled in this study from the University of Glasgow.

# Chapter 1. Introduction

## Rationale

This study is situated in the context of the ‘impact agenda’ for academic research, especially as this agenda has emerged and been institutionalised in the United Kingdom (UK). The UK’s performance-related research funding system, known as the Research Excellence Framework (REF), incentivises universities to conduct research and related activities that lead to demonstrable benefits for wider society. As discussed in greater detail later, this agenda emerged in the context of a ‘knowledge society’ (Etzkowitz & Leydesdorff, 1995; Wright, 2016), in which the research output of universities is perceived to be key to many of society’s needs and goals, such as related to the economy, communication, defence, health and environmental sustainability. The result has been that, since at least the early 1980s, academic research and related activities, as well as the governance of academic institutions more generally, have become matters of heightened political and social significance, and so too of political intervention in terms of influencing how academic institutions and activities are managed (Deem, Hillyard, & Reed, 2007; Martin, 2011). Key to this has been the logic of New Public Management that has characterised the last three or more decades of the UK higher education sector (and other sectors), and that has parallels across the globe (B. R. Clark, 1998, 2004b; Deem, 2004; Lambert, 2003; Shattock, 2017; Watermeyer & Olssen, 2016). Under these conditions, the behaviour of non-profit organisations, such as universities, is increasingly akin to that of businesses strategically steered by managers in response to perceived market dynamics and budget pressures (Rhoades, 2011; Slaughter & Rhoades, 2010), and where the objective of this steering is less the creation of conditions for academics to enact traditional values of free and critical inquiry, and more ‘productivity’ (Rhoades, 2001) gains vis-à-vis the indicators measured by assessments and league tables (Deem et al., 2007; Hazelkorn, 2007, 2008; Marginson & van der Wende, 2007). This has important implications for academia, not least the shift in the locus of authority and autonomy within universities; while academic managers are incentivised and empowered to exert influence on their institutions, autonomy for individual academics “is … secured through compliance with the … expectations of their institutions and funders” (Shields & Watermeyer, 2018, p. 10). This, however, is possible only for a part of the academic workforce, which is increasingly populated by fixed-term contract researchers tied to specific projects, academics who do not receive institutional support or time for research, and a loosely defined group of support professionals, many of whom have doctoral degrees and are involved in contributing importantly to academic ‘production’ but are not in traditional academic posts (Rhoades, 2001, 2011; Schafer, 2016; Watermeyer & Olssen, 2016).

There have been a whole range of analyses, critiques and studies around these developments and conditions. I want to emphasise two features in particular which, I argue, create a somewhat paradoxical situation for universities, and which helps to set the context for my own study. First, universities today are arguably more autonomous and independent than has historically been the case, at least at the level of individual institutions, as universities compete with one another for, among other things, research funding and prestige (B. R. Clark, 1998; Slaughter & Rhoades, 2010). Second, academia is more dependent than ever on the ability to produce knowledge and knowledge-related outputs of practical value to sponsors and other non-academic stakeholders (Cooper, 2009; Watermeyer & Chubb, 2018). The paradoxical situation this creates, then, is that, at the institutional level, universities appear to be enjoying significant, arguably even heightened status, relevance and autonomy, but they (are expected to) use this autonomy to address goals which are derived externally rather than internally (Henkel, 2007). This raises two types of problem.

First is an analytical problem, particularly a sociological problem: in the context of threats to academic autonomy and “integrity” (Deem et al., 2007, p. 166), in the sense of that which *integrates* and gives a *wholeness* of meaning to the many parts and participants of the university, a sociological explanation is needed for why the university persists as a distinct and central institution and how it continues to more or less successfully integrate disparate sets of actors (B. R. Clark, 1983; Gumport, 2000; Parsons, 1967; Parsons & Platt, 1973). The issue is not necessarily that such paradoxes should or could be done away with, but whether and how such paradoxes can “act as a source of stability” (Shields & Watermeyer, 2018, p. 11). To address this sociological problem, my main inspiration is the work of sociologist of education, Basil Bernstein. The above brief account of the current situation is suggestive of a complex interplay between academia and society in terms of the loci of ‘power’ and ‘control’ (Bernstein, 2000) over universities’ organisation, activities and external relations, that is, over the *boundaries* of academia. In this complex interplay, power and control could, on the one hand, be said to lie with academic institutions as they make autonomous choices about the extent to which their objectives, interests and activities should align with, address, or be guided by those of other, non-academic institutions and sectors; but on the other hand, power and control could be said to lie more with those external actors whose interests and objectives are shaping academic research.

The second problem is normative. Questions about whether the power and control over academic research are predominantly internal or external to academia go to the heart of debates around what counts as legitimate activity for universities, who counts as a legitimate shaper of academic research, what is meant by ‘academic freedom’ and autonomy, and how we should understand the university’s institutional identity and role (Barnett, 2017; Gunn & Mintrom, 2017). The point of departure for this thesis is my aim to bring empirical evidence to bear on the balance of power and control over the operation of academic research. To this end, I deploy the metaphor of academic ‘boundaries’ as a theoretical lens to frame my research.

The substantive study involves an analysis of documentary materials, supplemented by participant interviews, related to research based at a sample of ten UK science, technology, engineering, mathematics and medicine (STEMM) academic departments across nine universities. The analysis is driven by the aim of ascertaining the nature, intensity and challenges of ‘boundary transactions’ (see later theoretical discussion) associated with my sampled bodies of research (BoRs). By adopting a ‘bottom-up approach’ which starts by analysing the implications of specific ‘boundary transactions’ in their concrete contexts and then analysing these at a more aggregate level, I am able to increase the specificity and empirical basis for claims about the extent to which, and ways in which, academic boundaries may be being crossed, weakened and reshaped, or, alternatively, reinforced, strengthened, and reproduced – or, as it turns out, both simultaneously. In turn, this sheds light on the locus of power and control over academic research.

## Key concepts

### The ‘boundary lens’

My understanding of social boundaries draws mainly from the “neo-Durkheimian” (Fenton, 1984, p. 166) sociologist of education, Basil Bernstein, who provides a useful ‘boundary’ (Bernstein, 2000, p. xiii) lens for understanding contemporary systems, institutions and categories of knowledge, including academic knowledge[[1]](#footnote-1). However, I have also drawn from other sociological accounts of boundaries, including organisational and economic sociology and the sociology of science, as these provide somewhat more concrete theoretical insights into the interactions across boundaries. Briefly a social boundary, is a socially constructed device for regulating a relationship between two (or potentially more) categories, such as two categories of actor or group, or two categories of activity or domains of knowledge. For example, the discipline of physics is relatively bounded from that of chemistry or history, and we call those who hold authority over these knowledge domains ‘physicists’, ‘chemists’ and ‘historians’. At a higher order, ‘academic knowledge’ is relatively “bounded” (Henkel, 2004, p. 168) from non-academic knowledge, and we can use the collective term ‘academics’ to distinguish academic physicists, chemists and historians, etc., from those who hold no such authority over any domain of academic knowledge.

Boundaries reflect, and aim to preserve, the ‘power’ (Bernstein, 2000) held by a given group over some social asset or position. Academic boundaries “are conceptual and normative, as well as organizational. They serve to reinforce identification by highlighting differences from other groups” (Henkel, 2004, p. 168). However, there is no guarantee that boundaries will perform this function perfectly or indefinitely. As I will explain in greater theoretical detail later, a boundary is never a complete “insulation” from wider society or social phenomena – boundaries “attempt to regulate those who have access ... but, paradoxically, the device cannot do this effectively” since, “in controlling or attempting to control” access to a bounded space, the “power relations ... are ... necessarily subject to change” (Bernstein, 2000, pp. 30-31, 99). As such, that which is “bounded” (Bernstein, 2000, p. 99) is only partially protected from the complexities, politics and problems of wider society. No boundary can be completely self-sustaining; all social boundaries require some external validation and legitimacy; and all ‘bounded groups’, including groups whose boundedness is tied to their authority over a ‘bounded’ activity or “territory” (Henkel, 2007, p. 87) (domain of knowledge, such as physicists, history, etc.), have some pressure to show their value to wider society, or at least to some (relatively powerful) sections of it. In short, the reproduction of academic boundaries requires that academia continually has something to offer to (some of) those beyond its boundaries.

Any specific instance of this can be thought of as a ‘boundary transaction’. This is a key concept in my analysis. One example of a boundary transaction is the dissemination of an output of academic research to a non-academic site of activity. In this instance, what is given, what is ‘transacted’, is useful knowledge. Another ‘transaction’ could be the mobility of a graduate taking and applying academic skills in a non-academic workplace. Such transactions allow the bounded group to show its broader social value, thereby contributing to the legitimacy of, and therefore reproduction of, its boundaries. Boundary transactions do not have to take the form of outputs (either of research or of graduates). The appointment of an honorary professor based on their reputation in a non-academic sector fits my definition of a boundary transaction, in the sense that the university bestows symbolic status and, more instrumentally, provides the external actor the opportunity to shape the educational and/or research content of the relevant department. A new ‘boundary structure’ may also be understood as a kind of transaction with wider society, as they are symbolic and institutional announcements of the university’s entry, or at least partial entry, into a non-academic space. For example, a technology transfer office or a spin-out company signifies the university’s entry into the market as potential competitors with private companies. Similarly, a problem-focused research centre can signify entry into, say, areas of conservation management or commercial consultancy, to take examples from my own research.

One of the central ideas underpinning my study is that there is a constant interplay of ‘power’ and ‘control’ (Bernstein, 2000) between academia and wider society over the ‘transactions’ across academic boundaries. From the perspective of the boundary lens adopted, academia’s interest in transactions is the reproduction of its boundaries. By contrast, non-academic actors’ interest in transactions is the extraction of value from the bounded group. Although there is often a reciprocity between these two goals, they are not necessarily equivalent. As such, boundary transactions *may* serve to reproduce a given boundary, but they may also, over time, act as mechanisms for the “weakening” (Henkel, 2004, p. 168) of boundaries. If the bounded group becomes overly preoccupied with its external validation and valuation, there is a possibility that its activities, objectives and interests come to be almost identical with those of external actors, thereby losing its distinctive identity and potential value. A diagrammatic representation of these key conceptual relationships is presented in Chapter 2 (Figure 1, p.69) when discussing the analytical framework.

My study presents empirical evidence of how this interplay between power and control operates and, in doing so, contributes to (the often normative) debates around the current status of universities and academic research.

### The ‘knowledge-based’ view of the university

Underpinning my discussion so far has been an emphasis on universities as “knowledge-processing” (Gumport & Snydman, 2002, p. 380) institutions. This reflects the conceptualisation of the university as an institution grounded on its unique relation to knowledge, in particular what might be called ‘transcendental’ (Bernstein, 2000; see also Nickolai et al., 2012) knowledge, or what Young (2008) calls ‘powerful’ knowledge. This has implications for the conceptualisation and study of universities. Perhaps most significantly, it suggests that the main factor determining the development and evolution of universities is the proliferation and advancement of academic knowledge (B. R. Clark, 1983). This was emphasised as far back as Durkheim’s (2013) lectures on the university – arguably the first sociological analysis of higher education – in which he argued that the “*sui generis*” (p. 93, original emphasis) driving force of the European university had always been

“a profound feeling ... that the university would never fulfil its true destiny, would never achieve its true identity except in so far as it comprised a plurality or even the totality of the branches of human learning. It was ... an ideal ... towards which the university strove and was expected to strive. This is what we must not overlook if we wish to understand accurately the formation and development of the university. Over and above the external factors which brought it into existence and however these contingent factors affected it, as they certainly did with respect to the organisation of the university, there was still an *internal* phenomenon without which they would have remained more or less sterile” (p. 93, original emphasis).

This internal phenomenon is intimately tied up with the university’s unique relation to knowledge, whereby “knowledge is the ends as well as the means” (B. R. Clark, 1987, p. 268). B. R. Clark (1983) has characterised knowledge as the “invisible material” (p. 12) upon which universities are founded. Similarly, knowledge might be thought of as the invisible *character* in my study: the issue of how the knowledge base of society is organised, nurtured and mobilised (e.g. Bernstein, 2000; B. R. Clark, 1983; Etzkowitz & Viale, 2010; Gumport, 2000) underpins my interest in the topic, while the knowledge-centred view of the university has shaped many aspects of the study. For example, my decision to focus on STEMM disciplines was largely grounded in my effort to extend the ways in which existing analyses have taken epistemic content into account (see for example Hoffman, 2011; Slaughter & Leslie, 1997; Ylijoki, 2003). By limiting my study to STEMM fields, I have had greater scope to go into detail about the variation in knowledge content within STEMM, and made myself well-placed to explore the impacts of (relatively subtle) variations in knowledge content. My interest in knowledge content also informed my empirical approach, which was focused on capturing the *material traces* of this “invisible material” (B. R. Clark, 1987, p. 268), specifically, seeking these material traces in documents and webpages pertaining to the design, purposes, context, production, dissemination and application of STEMM academic knowledge (and supplementing these searches with participant interviews). Such documentary-led approaches, although not a majority, are becoming more common in higher education research (Brennan, Papatsiba, Sousa, & Hoffman, 2016). This focus on documentary sources, bounded by a focus on STEMM disciplines, enabled me to engage thoroughly with the epistemic content of my sampled research (see, for example, my narrative accounts of each ‘BoR’ in Appendix D) and use tools (i.e., the typology constructed by McNie, Parris and Sarewitz, 2016) consistently.

Another important concept associated with how academic boundaries are confronted, crossed and reproduced, but one which only emerged from later stages of the analysis of my research findings rather than one which I actively sought to explore initially, is that of ‘academic identity’ (Beck, 2002; Bernstein, 2000, 2001; B. R. Clark, 1972, 1983; Considine, 2006; Henkel, 2004). The interview data revealed that the academic identities of those academics involved in my sample of research, both in terms of their own sense of their academic identity and in the way that academic identities are perceived by non-academics, was an important factor influencing boundary transactions and, in turn, academic boundaries. Therefore, although my Discussion (Chapter 5) can draw some relevant conclusions about the role of academic identity, I am not able to do full justice to the apparent significance of this concept in this thesis. A greater focus on academic identity would require following in the footsteps of existing research that has made the perceptions, experiences and narratives of individuals more central to their analysis (Archer, 2008; Chubb & Watermeyer, 2017; Chubb, Watermeyer, & Wakeling, 2017; Watermeyer, 2015, 2016b).

## Contemporary context: The ‘impact agenda’ and the Research Excellence Framework

The REF is the UK’s quality-related research (QR) funding allocation mechanism. It runs approximately every seven years, the last being in 2014 and the next in 2021. REF2014 was the first in which the non-academic ‘impact’ of academic research was assessed. Although the introduction of the ‘impact’ element of the REF is only recent, it is a culmination of a much longer-term politically and economically driven agenda which coalesces under the term ‘impact agenda’. The inclusion of ‘impact’ is a significant manifestation and institutionalisation of the pressures and demands being faced by universities to produce useful or ‘impactful’ (Watermeyer & Hedgecoe, 2016, p. 652) knowledge by reorienting their organisation and practices towards societal rather than solely scientific problems and to generate and evidence their non-academic research impact (Martin, 2011; Watermeyer, 2016a). In the below sections, I (i) describe the REF2014[[2]](#footnote-2) process and the way in which it assessed ‘impact’, (ii) then take a step back to discuss the historical background to both the ‘impact agenda’ and the REF, as well as how these developments are part of broader forces towards increased accountability and production pressures and (iii) lastly, I theorise ‘impact’ through the Bernsteinian ‘boundary’ lens adopted.

### Impact in the Research Excellence Framework and its relevance to my study

REF2014 comprised four Main Panels, A to D, which group together a total of 36 Units of Assessment (UoAs), each representing a discipline or research field, or sometimes a group of related fields. STEMM fields fall under Main Panels A and B. Main Panel A (UoAs 1-6) covers disciplines related to health, biological and psychological sciences, and Main Panel B (UoAs 7-15) covers the physical sciences, mathematics, computer science and engineering fields (while the social sciences and the arts & humanities are covered primarily in Main Panels C and D, respectively).

Institutions are not assessed as a whole. Rather, individual departments submit their research to a relevant UoA, so that assessments are conducted at the level of individual submitting departments. Departments wishing to be assessed under a given UoA must submit evidence in support of three distinct areas: ‘Outputs’, ‘Environment’ and ‘Impact’. ‘Outputs’ refers to the quality of research outputs, such as journal articles, patents, or in some fields this might also include events such as performances. ‘Impact’ refers to the ‘reach’ and ‘significance’ of the non-academic impact which resulted from research – its official definition, as provided by the Higher Education Funding Council for England (HEFCE, 2009), which oversaw the REF until this role was passed on to the new body Research England in 2018, is “an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia”. ‘Environment’ refers to the size, sustainability and support for research within the department. The three areas are weighted as follows: the Output score contributes 65% to the total (although this is to be reduced to 60% in the next REF in 2021); Impact contributes 20% (to be increased to 25% in REF2021), and Environment 15%. Each of these areas are rated by the Panel according to the following classifications (detailed definitions of which are presented in Appendix A), in ascending order of quality: Unclassified (U/C), 1\*, 2\*, 3\* or 4\*. Thus, each submission’s final result takes the form of percentages of each starred level achieved in all three sub-profiles, contributing to an ‘Overall’ percentage of starred ratings. Table 1 presents an example:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Profile Type** | **4\*** | **3\*** | **2\*** | **1\*** | **U/C** |
| **Outputs** | 23.9 | 51.1 | 22.1 | 1.9 | 1 |
| **Impact** | 60.9 | 30.2 | 7.4 | 0.8 | 0.7 |
| **Environment** | 58.9 | 32.5 | 7.4 | 1.1 | 0.1 |
| **Overall** | **37** | **44** | **17** | **1** | **1** |

Table 1. Example of REF2014 submission result (all figures are percentages)

In support of the Impact submission, institutions submit Impact Case Studies, at a minimum of two Case Studies per submission, with more Case Studies required depending on the size of the submitting department. Impact Case Studies are four-page narrative documents which describe a body of research with references to relevant research outputs, and which detail and evidence specific impacts which resulted from that research. The descriptions and evidence of research outputs are provided in order to demonstrate how the submitting department’s contributions were crucial to the impact[[3]](#footnote-3). An online database, which is an output of the commissioned work by King’s College London and Digital Science (2015), is accessible via the REF website (<https://impact.ref.ac.uk/casestudies/>) and allows free access to these Case Studies.

For the purposes of my research, it is these Case Studies, or more specifically, the bodies of academic research which underpin them, that I am interested in. They represent a ready-made and well-reviewed database of bodies of academic research which have been recognised for their impact and which are therefore likely to include various boundary transactions. Moreover, the Case Studies describe the underpinning research in non-specialist terms, providing me with an accessible starting point to understanding the contexts and processes related to the bodies of research which I then study in greater detail in relation to their boundary transactions. The Methodology (Chapter 3) explains how I sampled Case Studies for analysis and what the analytical procedures entailed.

In the following section, I contextualise my study by introducing the background and recent history of the impact agenda in the UK. Much of the literature drawn upon in the following section is directly focused on issues arising from the impact agenda: how to operationally define and measure impact; impact policy evaluations; situating ‘impact’ in broader systems, policies and theories of research and academia; discursive or philosophical critique of ‘impact’; experiences of conducting ‘impactful’ research; the ‘impact of impact’, e.g. on research practice and institutional management. While this literature helps to contextualise my study and to highlight links to existing work, it is worth noting that, to a large extent, my own research does *not* aim tocontribute to this wide-ranging body of ‘impact’ literature. For example, it is not directly interested in issues of how to measure impact or how academic researchers and institutions should be assessed on their impact (Chowdhury, Koya, Philipson, & Dorta-González, 2016; Greenhalgh, Raftery, Hanney, & Glover, 2016; Gunn & Mintrom, 2017; Khazragui & Hudson, 2015; Klautzer et al., 2011; Ovseiko, Oancea, & Buchan, 2012). Nor do I aim investigate the conditions for impact or of good practices for generating impact (Denicolo, 2014; Grant, Brutscher, Kirk, Butler, & Wooding, 2010; Reed, 2017; Reed, Bryce, & Machen, 2018). Nor is my research an evaluation of impact policy (Martin, 2011) or its enactment in practice (Derrick, 2018; Samuel & Derrick, 2015; Watermeyer & Chubb, 2018) – although my research does have some implications for impact policy and its critique, as discussed in the Conclusion (Chapter 6).

Having said that, there are also many features and focal points that are shared between my research and the growing body of ‘impact’ literature. These include: a commitment to problematising the notion and role of the ‘user’ in research (Morton, 2015a, 2015b); a methodological decision to focus on research which has received high impact ratings in REF2014 in order to “make inferences about the kind of impact that was valued in the REF process, and the kind of research leading to such impact” (Laing, Mazzoli Smith, & Todd, 2018, p. 175); a greater interest in the *‘interactions’ (or what I call ‘transactions’) which underpin* impacts rather than in the impacts themselves (Akker, 2017; de Jong, Barker, Cox, Sveinsdottir, & Van den Besselaar, 2013; Molas-Gallart & Tang, 2011; Spaapen & van Drooge, 2011; Upton, Vallance, & Goddard, 2014; van den Akker & Spaapen, 2017); and an effort to understand differences in the experience and enactment of research impact across types of institution (Papatsiba & Cohen, 2019) and discipline (Upton et al., 2014). These shared features will be highlighted in the following sections and the remainder of Chapter 1.

### Background to and institutionalisation of the UK ‘impact agenda’

The REF’s predecessor, the Research Assessment Exercise (RAE), first ran in 1986, then was repeated every three to seven years. It was based on the view that such a QR funding allocation mechanism would improve the quality and thus the value of academic research at a time when the importance of academic knowledge for economic competitiveness was starting to become apparent to governments and industries across Europe and America, and when the UK government in particular was committed to demanding accountability of institutions in receipt of public funding (Etzkowitz & Leydesdorff, 1995; Martin, 2011; S. Smith, Ward, & House, 2011). Soon after the first RAE, the UK government began to increase their scrutiny of academic research, particularly on its economic impact. Originally, the steering of academic research took place somewhat indirectly, as the government introduced the requirement that research councils must consider the potential use(rs) of their funded projects and that applicants submit statements outlining intended ‘Pathways to Impact’ (Kearnes & Wienroth, 2011; Martin, 2003; Watermeyer, 2016a). While the focus on the economic impact of research councils continued (see for example Department for Business Innovation & Skills, 2010; Office of Science and Technology, 1993; Research Councils UK, 2007; Warry, 2006), by 2006 the government felt that more direct reforms were also needed in order to more dramatically reorient academic research towards the potential users of academic knowledge and towards socially and economically useful research, and this led, in 2008, to ‘impact’ being confirmed as a new element of the seventh round of research assessments, REF2014 (Department for Education & Skills, 2006; HEFCE, 2009; S. Smith et al., 2011). Since 2014, the political emphasis on impact has continued to grow, as the weighting of the impact element of REF2021 is increasing to 25%, up from its original weighting of 20%. The ability to achieve and evidence impact has therefore become increasingly important to the reputation and financial viability of academic departments and therefore to the career progression of researchers.

These intensified pressures upon universities are largely the result of such significant advancement and success for academic science that it has become too big, expensive and valuable an enterprise to be left to its own progress (Etzkowitz & Leydesdorff, 1999; Ziman, 2005/1994). The desire to achieve value for money from such a costly enterprise has meant that the ‘impact’ agenda has often been driven in tandem with other policy agendas, mostly focused on coordinating STEMM research power, such as the notion of research or technology ‘Foresight’ (Henkel, 2000; Martin & Irvine, 1989; Nowotny, Scott, & Gibbons, 2003; S. Smith et al., 2011) and, more recently in terms of ‘Grand Challenges’ and the ‘Industrial Strategy’ (Department for Business Energy & Industrial Strategy, 2017; Department for Business Innovation & Skills, 2014; Digital Science & Science Policy Research Unit, 2016; Science and Technology Select Committee, 2013; Stern, 2016). Perhaps most of all, the UK impact agenda can be understood in terms of the more general ‘third mission’ for universities – a parallel that has been drawn by many other authors (de Jong et al., 2013; Kitagawa & Lightowler, 2013; Perkmann et al., 2013). As Bacevic (2017) argues, UK universities’ research impact, as assessed in the REF, could be understood as a (partial) “measure” of their third mission (p. 8).

Although, ultimately, such policies and initiatives cannot force scientists or universities to reorient their work and activities, they do create an environment which, as some theorists have put it, operates “selectively” (Bernstein, 2000, p. 55; Leydesdorff, 2010, p. 370; Robertson, 2010, p. 193) upon knowledge production systems. Traditionally, the academic science system has operated as a relatively distinct and autonomous ‘field’ in which the primary aim of academics is to achieve, through published research and scholarship, distinction and prestige amongst other academics, who are at once peers and competitors (Bourdieu, 1975; Cooper, 2009; S. Smith et al., 2011; Turnbull & Antalffy, 2009). However, there has always existed the possibility of achieving success according to external criteria and demands, such as by producing knowledge which is useful to some group or institution or which generates income. For example, researchers’ “creative engagement with shifting structural conditions” (Cooper, 2009, p. 629) such as those presented by the impact agenda has manifested in an increase in the frequency of research which aims to meet both internal and external demands, and to fulfil both scientific and societal/economic criteria. This is reflected in the strong evidence that individual-level indicators of scientific quality and prestige are positive predictors of frequent engagement with non-academic users of research (Perkmann et al., 2013) and of ‘impact’ (Terama, Smallman, Lock, Johnson, & Austwick, 2016). The result is a normalisation and legitimisation of the idea that the conduct of ‘impactful’ research and engagement with non-scientific actors provide appropriate sources of financial support and scientific problems and that both sets of criteria ought to be valued and simultaneously pursued – indeed consideration of *use(rs)* is becoming fundamental to notions of academic research not only among policymakers and applied researchers, but to basic scientists as well, with more than one quarter of the 18,000 academics who responded to a recent survey categorising their research as ‘user-inspired’ basic research[[4]](#footnote-4) – the same proportion as ‘pure basic’ (Hughes et al., 2016, p. 31). This alliance between research ‘quality’ and research ‘impact’ is symbolically and practically institutionalised through the REF, as universities’ impact claims must be underpinned by research outputs of “demonstrable quality” (Stern, 2016, p. 22). The ‘impact agenda’, while it does not de-legitimise academic standards of excellence, can therefore be said to operate selectively upon the system in such a way as to increasingly privilege and celebrate research which achieves or is oriented towards external goals and values, or in other words, towards impact. My academic interview respondents reveal some stark instances and effects of this (see Chapter 4).

Mediating these policy-driven structural conditions and individual-level effects is the crucial and increasingly visible and active role of institution-level management and administration. In the UK, the increasing prevalence and transparency of the terms of institutional competition, such as the ratings and rankings associated with the RAE/REF and global and national league tables (Hazelkorn, 2007, 2008; Marginson & van der Wende, 2007) has been matched by the increasing centralisation of academic management capacity (Shattock, 2014, 2017). The ‘Jarratt Report’ (Committee of Vice Chancellors and Principals, 1985), the ‘Dearing Report’ (National Committee of Inquiry into Higher Education, 1997) and the ‘Lambert Report’ (Lambert, 2003) represent three decades of officially-sanctioned landmarks in this tendency towards a stronger central authority – the first and third of which also explicitly focus on how university management can promote university-industry relations. Across Northwestern Europe and English-speaking nations, academic managers are increasingly incentivised and empowered to exert influence on their institutions and staff in pursuit of externally-generated income and markers of prestige (Bleiklie, 1998; B. R. Clark, 1998; Deem et al., 2007; Graham, 2014; Marginson, 2008; Marginson & Considine, 2000; Slaughter & Cantwell, 2012). While universities in these countries have in the past often been able to obviate difficult decisions about reducing or removing certain activities simply by adding to existing structures and activities whenever a new demand perceived to be significant and legitimate emerges, the current climate calls for a more strategic and professionalised approach to organisational management and innovation (Ben-David, 1977; B. R. Clark, 1983, 2008/1961; Gumport, 2000; Nelles & Vorley, 2011; Sporn, 1995). For example: human resource decisions shift from being guided by internally-defined academic criteria to being guided by externally-defined criteria, taking a more strategic and proactive effort to attract personnel who will improve performance on, say, the REF (and excluding staff who will not) (Schafer, 2016; Stern, 2016; Watermeyer & Olssen, 2016); institutions experiment with organisational innovations such as the integration of sub-disciplinary research groups into interdisciplinary, problem-oriented research centres (B. R. Clark, 2004a; Ponomariov & Boardman, 2010; University College London, n.d.); universities seek new sources of revenue and prestige or ‘scholarly distinction’ (Watermeyer & Chubb, 2018) through ‘impact’, knowledge transfer and commercialisation with the support of technology transfer offices (Etzkowitz, 1983; Glenna, Lacy, Welsh, & Biscotti, 2007; Slaughter & Rhoades, 2010); marketing offices and their campaigns are expanded and increasingly professionalised and strategic (Pusser & Marginson, 2013; Rhoades, 2016). Each of these adaptations and innovations are symbols of an organisation’s commitment to the legitimacy held by and, they hope, bestowed by, externally-generated discourses (B. R. Clark, 1983; Gumport, 2002; Hoffman, 2011; J. W. Meyer & Rowan, 1977; Pettigrew & Starkey, 2016).

### Analysing the impact agenda through a Bernsteinian ‘boundary’ lens

Commentators have noted “ambiguities” (Pinheiro, Benneworth, & Jones, 2012, p. 13; Watermeyer & Chubb, 2018, p. 10) associated with the impact agenda and related imperatives, ultimately deriving from the paradoxical situation whereby academia is, on the one hand, bounded from wider society and operates somewhat autonomously according to internal criteria of success, while on the other hand, academia is being increasingly challenged, pressured and influenced by non-academic standards, producers and users of knowledge who have different values, missions and success criteria (primarily based on economic value). The Bernsteinian ‘boundary’ lens adopted in this study, introduced briefly in Chapter 1 and elaborated in Chapter 2, puts these ‘ambiguities’ in an interesting light, by showing that ambiguity is unavoidable because the underpinning tensions are unavoidable, even *necessary*. Like all institutions, academia’s boundaries cannot be completely self-sustaining; although grounded primarily on a close relation to ‘transcendental’ knowledge (Bernstein, 2000; see also Nickolai et al., 2012), academia cannot survive if it ignores the everyday; boundaries must, at least occasionally, be crossed, and this “can create ambiguity” (Bernstein, 2000, p. 17). The impact agenda is therefore a symptom as well as a cause of the issues facing universities.

This does not mean that ‘impact’ as a policy, dominant discourse or objective is necessary or unavoidable. Indeed, Bernstein (2000) was deeply critical of what he saw as governance mechanisms such as the REF (at his time of writing, the RAE) promoting practices which “threaten” academic boundaries, such as incentivising “short-term … low-risk” research which aim more at supporting “the activities of funding agencies” than contributing to the “[l]ong-term” stock of knowledge (pp. 52, 63). This perspective on the impact agenda as a *non-necessary* manifestation of *necessary* underlying tensions provides a grounding for critiquing and, if necessary, resisting impact policies, not because the intention of promoting and enabling the social benefits of research to be realised is itself problematic, but because these policies often ‘misrecognise’ (Bernstein, 2000, p. 53) how these benefits arise and risk not only the long-term integrity of academia but also the long-term potential for academia to provide ‘useful’ knowledge. ‘Misrecognition’ is where attempts to understand complex realities are reduced to a narrow, purely “functional analysis of what is taken to be the underlying features necessary” to “perform” (Bernstein, 2000, p. 53) or achieve a certain task or objective, say the generation of ‘impact’. In the context of the UK impact agenda, ‘misrecognition’ might lead to narrow views that ‘impact’ is somehow the result of ‘best practice’, compliance with REF procedures, alignment with values espoused by the REF and wider policy discourse, etc. Such misrecognitions fail to appreciate the contextual specificity, comprised of complex institutional, epistemic and sociocultural elements, as well as idiosyncratic personal and interpersonal elements, in which the interactions and collaborations underpinning research impact came to be seen as appropriate, legitimate and worthwhile for those involved (Oancea, Florez Petour, & Atkinson, 2017). There is therefore a need for research which aims to understand what is actually happening in the process of what our systems designate as ‘impactful’ research. One of the main reasons for the qualitative approach and small sample selected for my study is to capture some of these contextual elements, and to show that boundary transactions must be *recognised* in their full complexity, as part of the necessary tension of the academic enterprise, rather than *misrecognised* as merely a way to ‘perform’ impact.

## The study

### Research questions, assumptions and expectations

I am guided by one overarching research question and three implied or developmental sub-questions. The main research question is:

*What is the balance of ‘power’ and ‘control’ over the organisation, activities and societal relations associated with ‘high-impact’ academic STEMM research in the REF2014 context?*

Sub-questions:

1. *What role do different institutional and epistemic contexts play in shaping the balance of ‘power’ and ‘control’ over academic STEMM research?*
2. *What are the main forms and functions of ‘boundary transactions’ associated with the sampled academic STEMM research?*
3. *What are the implications of the balance of ‘power’ and ‘control’ for academic boundaries in the context of the ‘impact agenda’?*

In answering these research questions, I contribute to an understanding of how academic boundaries persist, albeit in potentially adapted form, despite decades of pressure on these boundaries, and significant evidence of their loosening, weakening and blurring (see the Literature Review, Chapter 2). Moreover, by positing theories about the underpinning mechanisms which shape this reproduction, and the contingent conditions under which they have this reproductive effect, I draw out implications for the ongoing development of academic boundaries and how they may be experienced, confronted and crossed in the future.

There are some underlying assumptions behind these research questions that are worth stating:

* The metaphor of ‘boundaries’ and associated notions of ‘boundary transactions’ and of boundaries being reproduced, weakened, reshaped, etc., are valid in relation to understanding universities’ research-related activities and relations with wider society and non-academic institutions.
* My analytical procedures are capable of providing reliable evidence pertaining to how research contributes to the reproduction of academic boundaries.
* Research is a complex and multi-dimensional activity such that certain aspects of research might contribute to the reproduction of academic boundaries whilst others might simultaneously contribute to (the potential for) their weakening.
* ‘Boundary transactions’ can be a mechanism through which boundaries are regulated, reproduced and maintained, but also through which they can be crossed, reshaped and weakened.
* Discipline and type of institution, i.e. the mission and prestige of the department and the wider university, are likely to have some influence on almost every aspect of an academic researcher’s work and experience.

It is also important to articulate some of my prior expectations of the research:

* I expect to find much evidence of research-related boundary transaction and therefore of ways in which academic boundaries are being crossed and potentially weakened.
* However, given the longevity of universities and their arguably increasing centrality to society, I expect that my research will find evidence of research activities overall contributing to the reproduction of academic boundaries.
* I expect that researchers will experience and confront boundaries differently in more and less prestigious institutional settings. For example, the challenges associated with confronting and crossing boundaries may be greater for researchers in less ‘powerful’ institutions, although I do not expect this to be a neat correlation.
* I also expect that disciplinary differences may be likely, although it is difficult to predict how these differences will manifest.

### Approach and importance of the study

The study involves purposefully sampling ten academic departments from nine UK universities whose research has been recognised for its ‘impact’ in REF2014. The departments capture a range of institutional types and a range of STEMM fields. The main empirical analysis focuses on the specific ‘bodies of research’ (BoRs) which underpinned the departments’ REF2014 Impact Case Study submissions. In total, I analyse n=19 BoRs from the ten departments. I gather a range of documentary materials related to these BoRs, supplemented by participant interviews with researchers involved. The documentary materials include: information about the research and the department submitted to REF2014; outputs from the underpinning research; other information about the research such as grant proposals or press releases; and web pages about the research, the individual researchers or research units involved, as well as web pages related to any non-academic actors involved in the research (for example who were mentioned as playing an important role in the REF2014 documents, or who were acknowledged in academic outputs as collaborating or otherwise supporting the research, or who interview respondents mentioned as being important). In total I gathered 345 documentary materials for analysis and conducted 10 interviews. The Methodology (Chapter 3) and Appendix B provide further methodological details related to sampling and the collection and analysis of data, while Appendix C lists all documentary materials.

This research is timely and relevant, given what is potentially at stake in current debates about the extent and legitimacy of external influences on universities’ activities, including research. To highlight the importance of the research, I will briefly highlight three such ‘stakes’ of current debates about, and apparent shifts in or reshaping of (Wright, 2016), ‘academic boundaries’, and provide some indicative references to these debates in the literature.

First, what is at stake is the capacity of universities to be sufficiently bounded from society to allow space for advanced research and learning, whilst not being so strongly bounded as to lose relevance to wider society. On one side of the debate is what could be termed the ‘social value’ critique of universities, which considers academic boundaries, including disciplinary boundaries, as obsolete, arbitrary and self-serving in the face of goals of innovation and Grand Challenges. On the other hand, there is evidence that existing academic boundaries are important for ease of communication amongst academics and socialisation of new academics, and therefore also to the epistemic organisation of knowledge and the formation of important academic identities and values which underpin objective and reliable inquiry. (For literature on these debates, see Barry, Born, & Weszkalnys, 2008; Ben-David, 1971; Bernstein, 1971, 2000; Biglan, 1973; B. R. Clark, 1983; Golinski, 2008; Gornitzka, 2003; Henkel, 2004; Kohler, 1999; Krishnan, 2009; Metcalfe, 2010; Schaffer, 2013; Trowler, Saunders, & Bamber, 2012; Ziman, 2000)

Also at stake is the issue of which actors and interest groups are (re-)shaping the boundaries and goals of academia in the context of the impact agenda. On the one hand, there is evidence that shifts in the impact-orientation of academic research is largely internal, simply a reflection of shifts in the attitudes and objectives of academics themselves, who increasingly see close involvement with users, beneficiaries and contexts of application as a legitimate mode of research (Abreu, Grinevich, Hughes, & Kitson, 2009; Hughes & Kitson, 2012; Hughes et al., 2016; Morgan Jones, Manville, & Chataway, 2017; Watermeyer, 2011, 2012). On the other, there is concern that such behaviour is the inevitable response to significant external pressure, such that the content of academic research is being disproportionately influenced or even co-opted by already powerful social actors (Barnett, 2017; Langley & Parkinson, 2009; McNie et al., 2016; Watermeyer, 2016a).

Third, at stake are the careers, motivations and wellbeing of individual academics. For example, there is evidence of significant negative reactions to the impact agenda, centring on the perceived incompatibility of discourses of impact with the values and aims that have traditionally guided academic work, and even, paradoxically of incompatibility of the impact agenda with the values that have provided motivation for academics’ external engagement (Chubb & Watermeyer, 2017; Watermeyer, 2014). On the other, there is evidence that the increased incentives and support that the impact agenda encourages for reaching out across academic boundaries are proving to be liberating and productive for many researchers, particularly those who have always seen engagement and impact as a natural part of their work but have perhaps not been rewarded for this in the past (Morgan Jones et al., 2017).

These indicative debates raise dilemmas about academic boundaries and the extent to which they have and should shift or loosen. They call for efforts, such as mine, to explore empirically how interactions across boundaries are playing out, and with what consequences.

## Thesis structure

The present chapter has introduced the thesis and the key concepts and ideas used. The study focuses on aspects of universities’ research-based relations to wider society. It uses the context of the ‘impact agenda’ as a lens and a focal point for the study. I operationalise this focus primarily by using data within REF2014 submission documents and results as part of my sampling procedure and my corpus of documents for analysis. In particular, the departmental Impact Case Study documents, publicly available at [https://impact.ref.ac.uk/casestudies/](https://impact.ref.ac.uk/casestudies/t) thanks to the work of King’s College London and Digital Science (2015), provide me with an initial ‘way in’ to bodies of STEMM research which involved significant ‘boundary transactions’ and have received official recognition for their ‘impact’.

Chapter 2 is a systematic review of relevant theoretical and empirical literature, split up into three sections and leading up to a fourth section which presents the analytical framework. The chapter’s *first* *section* outlines the Bernsteinian ‘boundary lens’, presenting my application of the key Bernsteinian concepts of ‘power’ and ‘control’, and highlighting the differential power and control across academic contexts as part of the justification for my decision to purposefully sample from distinct academic research contexts. It also introduces the key causal mechanistic concept of ‘boundary transactions’. The *second section* makes the forms of academic boundary transaction its central focus. It is organised around five main forms of boundary transaction identified in the literature. These main forms of boundary transaction are ‘outreach’, ‘collaboration’, ‘use-oriented outputs’, ‘boundary structures’ and ‘boundary-spanners’. The *third* section emphasises that boundary transactions do not take place in a vacuum but in the context of actual research activity. In order to understand boundary transactions, it is necessary to understand how they function in their particular contexts of research. But research is inherently complex and multidimensional. This section therefore focuses on a typology constructed by McNie et al. (2016) which can be used to produce a codified description of a given ‘body of research’ (BoR). Developing a codified conceptualisation of my sample of BoRs provides a basis for understanding how boundary transactions operate across different contexts. The *fourth* and finalsection draws on elements of the previous three to present an analytical framework. A fuller description of the analytical procedures and their relation to the critical realist epistemological framework adopted is presented in the Methodology (Chapter 3).

Chapter 3 is the Methodology chapter, describing the research design and the sampling procedure, as well as providing more detail about the analysis. I position my research within the metatheoretical framework and ontological and epistemological standpoint of critical realism. The chapter also addresses the limitations and the ethical issues of the study.

Chapter 4 (Analysis and findings) presents the findings. It involves both descriptive, empirical analysis and more interpretive, explanatory analysis. Rather than break down the different elements of the analysis into separate chapters, I chose to keep all analysis within one long chapter with distinct sections. The *first* *section* of analysis starts with some of the empirical findings of the ‘interpretative quantitative’ analysis (Babones, 2016; Westerman & Yanchar, 2011) of the data generated from the typology; my slightly adapted version of the typology captures the extent and nature of the ‘boundedness’ of the sampled research, taken to be an indicator of its tendency towards the reproduction (in the case of ‘bounded’ research) or weakening (in the case of ‘unbounded’ research) of boundaries. It then examines the role of boundary transactions in producing these results. The *second section* presents an in-depth illustrative analysis of three of n=19 BoRs sampled. This allows me to go into detail about how I read, interpreted and coded the BoRs. It therefore gives the reader greater access to the research process. It also provides me with an opportunity to illustrate some concepts used in the analysis which are difficult to convey without examples from the complex reality of research. For illustrative purposes, I select the BoR with the highest overall typology value, the lowest value, and the middle value, conceptualised as examples of ‘bounded’ research, ‘unbounded’ research, and ‘moderately bounded’ research, respectively. The *third section* moves towards a more explanatory analysis. It draws on more detailed readings of the documentary data and, crucially, the qualitative interview data in order to seek some of the underpinning factors shaping the results. It is organised around a focus on the contexts of research and variations within different contextual categories, i.e. variations between different institutional and epistemic contexts. The idea is that by homing in on underpinning reasons for variations between one context and another, I will better be able to identify the most salient underpinning structural forces shaping academic research and the reproduction or weakening of academic boundaries.

Chapter 5 (Discussion) discusses the plausibility of explanations put forward in the Analysis (Chapter 4) in relation to existing empirical and theoretical literature. This chapter summarises my insights into the balance of ‘power’ and ‘control’ over academic research and academic boundaries, addressing both internal and external sources of power and their interplay, as external power is differentially mediated by the (institutional and epistemic) context of academic research.

Finally, Chapter 6 concludes the thesis. It summarises the findings and considers their implications for academia and the future of academic boundaries. One of the main findings is that my evidence points, on balance, towards power and control over academic boundaries and boundary transactions lying mainly within academia rather than with external sources acting upon it, and therefore the research-related boundary transactions tend towards the reproduction of academic boundaries. But it also finds evidence of both internal and external sources of tension which should prevent this reproduction from being taken for granted.

# Chapter 2. The ‘Boundary’ Lens: Empirical and Theoretical Literature and an Analytical Framework

## Introduction

This chapter is broken down into four main sections. The first three draw from existing literature to discuss different aspects of academic boundaries and boundary transactions associated with academic research, while the fourth distils these three elements and combines them into an analytical framework. To elaborate*, the first* section is primarily theoretical, focusing on the ‘boundary’ metaphor as a lens through which to study concepts of ‘power’ and ‘control’ over academic knowledge, research and related activities. As explained in Chapter 1, I understand boundaries to have the function of (i) demarcating a social space or activity over which a certain group holds relative ‘power’ and ‘control’, but (ii) so as to *regulate* the relationship of this group to wider society, rather than entirely isolate or dislocate them (Bernstein, 2000). From this perspective, the key empirical focus in the study of boundaries is the ‘transactions’ across boundaries, since boundaries are reproduced and/or reshaped through the interplay of power and control over the nature and manner of these ‘boundary transactions’. *The second* section reviews existing literature in order to identify key forms of ‘boundary transaction’. Many, although not all, of the authors referenced here write specifically in terms of the metaphor of ‘boundaries’, while a few write in terms of ‘transactions’. This section of the literature gives some indication of how boundary transactions play out in actual contexts of academia’s relations with wider society. This literature review helps to orient and contextualise my empirical analysis. *The third* section emphasises the importance of acknowledging the multi-dimensional complexity of research activity as a site of boundary transactions. This is addressed primarily with reference to the findings of McNie et al.’s (2016) own extensive literature review and collective experience as scientists, science users and science policy decision makers and advisers in North America. McNie et al. (2016) synthesise this knowledge and experience in a typology made up of fifteen attributes and activities which, combined, allow a holistic picture of the research process in its complexity. The typology offers “a systematic framework” for comparing the relationship between “knowledge generation” and “stakeholder and user engagement” (McNie et al., 2016, p. 885). Being able to work with this complexity is important if I am going to understand the functioning of boundary transactions in their actual contexts. *Lastly*, I summarise the key lessons and insights from the first three sections as I present the *analytical framework* which guides my empirical analysis.

## Power and control through the ‘boundary’ lens

### Boundaries and ‘power’

As discussed briefly in Chapter 1, social boundaries are socially constructed devices for regulating a relationship between two (or potentially more) categories, such as two categories of actor or group, or two categories of activity or domains of knowledge. Boundaries reflect and aim to preserve the ‘power’ (Bernstein, 2000) held by a given group over some privileged social asset or position. Such power, and the ability to reap advantages from it, such as advantages in the form of symbolic and social capital, are scarce. As with anything which is relatively scarce and valuable, its distribution is a social problem, that is, it is an issue which is to be decided through social processes, social mechanisms and the construction of social institutions and norms. The social structures, groupings and norms which arise as a result of struggles to solidify the access to such scarce resources, can therefore be thought of as social solutions to socially faced problems (Tilly, 1998). This is how social boundaries are to be understood.

Boundaries can exist wherever sufficiently powerful actors or groups have a stake in their production and “*maintenance*”, that is, whenever sufficiently powerful groups are sufficiently motivated to “regulate” the relation between two or more categories (Bernstein, 2003/1990, p. 95, original emphasis). A boundary implies that there is something worth regulating and, therefore, potentially worth struggling over: the definition and demarcation of a ‘boundary’; what counts as ‘inside’ or ‘outside’; characteristics such as the ‘strength’, ‘porosity’ and ‘flexibility’ of a boundary – all these are potential sites and sources of struggle, because something about that boundary has value to one or more groups.

Social boundaries do not have to refer to boundaries between groups but can refer to boundaries and divisions between any meaningful “categories” (Bernstein, 2000, p. 6). However, where the boundary is not between two (or more) well-defined ‘groups’, it is still likely to be the case that some group has a particular stake in the maintenance of that category. For example, the discipline of physics is a category related to knowledge about certain natural phenomena, but there is also a group, referred to as physicists, who are defined by their authority over that domain of knowledge, and therefore with the greatest interests in the maintenance of the boundaries associated with their discipline.

Boundaries may or may not be formal or legal boundaries. They may rather be based more on norms, expectations and patterns of activity. There may also be a blend of formal and informal regulations. For example, while there may be no formal rules preventing the historian from making claims to knowledge of physics, there are formal bureaucratic realities which classify academic expertise, for example job titles.

In general, the existence of boundaries is not inherently negative or positive. In one sense, boundaries are always *productive*, in the earlier sense that they ‘solve’ (albeit not indefinitely) socially faced problems. This ‘productive’ element even goes for instances in which boundaries have horrific consequences for humanity. For example, historian John W. Cell (1982) analysed the history of racial segregation in South Africa and the United States. He explains that the concept of segregation emerged not at a time when there was a genuine segregation, that is, a genuine separation between the two ‘races’; rather, segregation as a policy, and even usage of the term itself, only emerged when the level of interaction between them made acute the problem of regulating their interrelationship. Cell’s (1982) perspective therefore sees segregation as a special form of ‘integration’, one that is based on heavily regulated boundaries (regulated by both law and racist ideology).

Coming back to the case of the discipline of physics, boundaries can also be productive in that there can be benefits from allowing distinct and bounded categories “a space in which to develop their unique[ness]” (Bernstein, 2000, p. 6). The construction and maintenance of boundaries around this domain of knowledge allows a space for dedicated specialisms to develop in which knowledge of the physical world can advance, and new physicists can be trained. Even in such benign and positive cases though, boundaries may still be conceived as having constraining effects. This is the line of argument that sees disciplinarity as obsolete and as preventing, say, physicists, from engaging in the kinds of learning and collaboration that allows them to put their knowledge to use in applied contexts, by focusing physicists’ attention on narrow goals such as citation counts and reputation amongst immediate peers (McNie et al., 2016).

For Bernstein (2000), whether academia comes to afford relatively less focus on disciplinary knowledge and correspondingly more attention “outwards”, say on “fields of practice”, is determined by power (pp. 34, 55). It “is *power*” (Bernstein, 2000, p. 6, original emphasis) that determines the strength of a boundary. He even goes so far as to state that: “*the distribution of power maintains itself essentially through the maintenance of the appropriate degree of insulation between the categories ... it legitimizes*.”(Bernstein, 2003/1990, p. 95, original emphasis). In short, the reproduction or increase in the insulation and strength of academic boundaries reflects the internal power of the bounded group, or the group which has authority over the bounded category (i.e. domain of knowledge or activity). By contrast, a weakening of boundaries reflects that the power of this group has waned relative to outside actors, who either aim to hold authority over that category themselves, or else wish to exert influence over the group that holds authority.

The issue to be raised at this point is how and why bounded groups, or groups holding authority over bounded categories of knowledge or activity, might allow themselves to be influenced in this way; how and why might academic boundaries come to be weakened? In short, the answer is that some level of external influence is unavoidable. The nature of social boundaries requires some level of porosity, that is, there must be some mechanism for linkage and exchange between the bounded category and wider society (albeit in a ‘regulated’ way), and this means there is always the potential for weakness. To explain this, particularly in relation to academic boundaries, requires deeper theoretical discussion invoking the legacy of Émile Durkheim, often regarded as the first to apply sustained sociological thought on issues of education and the university (Bernstein, 2000; B. R. Clark, 1983; Young, 2000).

In *The Elementary Forms of the Religious Life*, Durkheim (1915) was originally interested in the formation and integration of societies. Just as I posed the persistence of the integrity of universities as a sociological problem, so did Durkheim see societies as particular social forms which, rather than being natural or obvious, were produced and sustained through particular forms of collective human activity and organisation. As such, they presented an intellectual problem and required an explanation. He posited a sociological explanation which emphasised the relationship between individuals and the institutions which they collectively construct. Durkheim (1915) was therefore interested in how social forms and institutions achieved a sense of moral solidarity and the cohesion of disparate individuals into a society.

His starting point was to acknowledge that the idea or concept of a society necessarily transcends the idea of the individual, and even transcends the idea of multiple individuals. This is because society implies not only a multiplicity of individuals, but a multiplicity of individuals who are linked to each other in particular ways, in which they are *not* linked to other individuals who fall outside of this multiplicity (for example, those in neighbouring ‘tribes’). As such, the construction of a society out of disparate individuals necessitates that these individuals participate in a *collective cognitive act*, that is, they must all come to some understanding of their collective selves as mutually belonging to a common collective, i.e. a society. What was needed was some kind of intermediary concept that transcended any given individual but was sufficiently tangible for disparate individuals to cohere around.

Durkheim (1915) introduces the ‘sacred’ as just such an intermediary concept through which this collective cognitive act can be achieved, and through which a shared conceptualisation of society can become manifest. For Durkheim (1915), those objects, phenomena, activities, rituals, persons, ideas and beliefs which come to be classified as ‘sacred’ in any given collective are precisely those which come to symbolise the “idea of society” (p. 347); the ‘sacred’ is the symbolic “ideal ... expression of the whole collective life” (pp. 419-420). For our purposes, it is not particularly relevant to consider the specifics of why any such phenomenon, object, event, etc. may come to be classified as sacred rather than another. What is important is to appreciate the function of the ‘sacred’ as having this special symbolic meaning. This meaning makes it distinct from the non-sacred objects, phenomena, activities etc. of everyday life, that is the ‘profane’.

Bernstein, and later his students, emphasised, elaborated and, to an extent, generalised aspects of Durkheim’s model. First, Bernstein (2000) emphasised that these two classes, the sacred and the profane, are in fact classes of *knowledge[[5]](#footnote-5)*. To the extent that the objects, events and phenomena which are classified as sacred are understood by a community to have transcendental symbolic meaning, which unites and gives order to their everyday existence, then it is effectively a class of abstract, “transcendental” (Bernstein, 2000, p. 29) knowledge, distinct from the “mundane” (Bernstein, 2000, p. 29) knowledge of everyday life. As Young (2008), a student of Bernstein’s, explains, the ‘sacred’ therefore provides society with “the model for all the other types of abstract thought, such as modern science, that consist of unobservable concepts” (p. 41). Thus, from this theoretical perspective, the cognitive act of classifying the ‘sacred’ as distinct from the ‘profane’ is simultaneously an act of constructing a system for “specialised, symbolic structures of explicit knowledge” which transcends the unsystematised knowledge of “everyday” experience (Bernstein, 2000, pp. 29, 160). In other words, this collective cognitive act institutionalises a system of specialised, transcendental knowledge. In this respect, it is therefore a precursor to all modern systems of specialised, “esoteric” (Bernstein, 2000, p. 29) knowledge and transcendental thought, including that which modern societies have organised into academic disciplines. Academic institutions such as universities and the disciplinary groupings which they house are arguably the primary institutions through which contemporary society pursues “transcendental” thought – or through which society “partakes of the sacred” (Beck & Young, 2005, p. 185).

Bernstein (2000) also noted that the boundary separating the sacred from the profane, and by extension that separating the transcendental from the everyday, is not a complete “dislocation” (p. 30). Despite the existence of boundaries, there must necessarily also be some channel or mechanism for the boundary to be crossed, for there to be some level of mutual (although not necessarily equal) influence from either side of the boundary. This must be so since although the ‘sacred’ functions to transcend and unite individuals, it is ultimately individuals who collectively are responsible for the construction of the symbolic, specialised, esoteric system – they may transcend us, but they “have their roots in us” (Durkheim, 1915, p. 420). The construction of systems for specialising in the transcendental involves the construction of boundaries around the transcendental; but such boundaries are themselves *bound* to an everyday context, since they are ultimately grounded in, and give meaning to, everyday life. Bernstein therefore generalises Durkheim’s concepts. The ‘sacred’ and the ‘profane’ become, more generally, the transcendental and the everyday.

There are a few implications of the above discussion for how I have understood and applied the idea of academic boundaries in this study. First, a bounded category can never be defined purely in its own terms. Any category is always defined not solely in terms of what it claims to be, but rather must be defined *relationally*, that is, in relation to what separates it from other similar or opposing categories. Hence, any boundary is contingent upon a relation to that which exists outside it. Second, the construction, maintenance and reproduction of boundaries requires *work* (hence the concept of 'boundary work', e.g. W. C. Clark et al., 2016; Gieryn, 1983; Nickolai et al., 2012; Pawley, 2012; Rödder, 2017). A sufficiently powerful interest group, or a sufficiently large quantity of people in wider society, must have sufficient interest in the boundary if the boundary is to be maintained and reproduced. The reproduction of the boundary is thus a function of the power of the group(s) with the greatest stakes in its reproduction, the amount of work these groups are ready to put into its ongoing legitimacy, and the power of other groups with an interest in potentially weakening or re-shaping these boundaries. However, and thirdly, there is no such thing as a perfectly bounded category. There must always be some form of relation, something that the reproduction of the boundary *gives* to wider society. I have called this a ‘transaction’ and will take this concept up further below. What is ‘given’, what is ‘transacted’, can vary greatly. For example, the ‘sacred’ gave a moral order and solidarity to society at large; for academia to legitimise its boundedness, it too must be seen to give something, say the preservation, transmission and generation of knowledge perceived to be of cultural or economic value. However, and fourthly, precisely because such cross-boundary transactions are a necessary feature of boundaries, this also means there is always a potential opening, a ‘porosity’ and a potential for weakness in boundaries. ‘Transactions’ are potential ‘weak spots’ for bounded categories or entities, including academic boundaries.

From this perspective then, the main site for analysing the interplay of ‘power’ and ‘control’ and the potential shifting, re-shaping or weakening of boundaries is that of ‘boundary transactions’. For the bounded category, transactions are a mechanism for regulating the relation between itself and wider society, that is, they are attempts to take control over that relationship. This is because neglecting transactions and becoming fully insular is not a viable, sustainable alternative for the reproduction of boundaries. The alternatives of not taking control over boundary transactions are either that the boundary’s legitimacy is not apparent to wider society, or that another group or groups will take control over these transactions and may therefore hold greater power over the bounded category.

For example, if academia was to (re-)enter an ‘ivory tower’ mode in which it attempted to significantly strengthen its boundedness and autonomy from wider social considerations, this would not be a genuine isolation. Rather, it would represent a potentially risky strategy at maintaining power over its domain of knowledge and knowledge-related activity vis-à-vis wider society. It is risky not because academia excuses itself from the need to transact, but rather because, in the words of an insightful report by the OECD Centre for Educational Research and Innovation (CERI, 1982), “even the phenomenon of the “ivory tower” must be understood in terms of interaction, not as a symbol of an illusory independence” (p. 17). That is, the ‘ivory tower’ image is itself a transaction, but one which rests on wider society’s agreement that academia’s legitimacy is based solely on its relation to the ‘transcendental’ (Nickolai et al., 2012). It is not predetermined that such a strategy will fail, but such a strategy leaves open the possibility that other knowledge-based institutions may gain in ascendency by ‘transacting’ knowledge and knowledge-based outputs in more innovative and interventionist ways which society sees as more valuable than that transacted by an ‘ivory tower’ institution. The point of this is not to make a normative argument either against or in favour of an ‘ivory tower’ model of the university, nor against or in favour of alternative institutions challenging universities as prime knowledge-based institutions. Rather, the point is that transactions across boundaries are unavoidable, and that the reproduction of boundaries may be better achieved by taking control of these transactions than by attempting to minimise their frequency or intensity.

Of course, there is also the potential for an alternative extreme approach, whereby universities increase the frequency and intensity of boundary-crossing transactions and engage in more direct interventionist activities perceived by some to be out of keeping with their expectations of universities. In such cases, the university, or any bounded institution or group, is “in danger of losing its identity” (Bernstein, 2000, p. 6). The risk here is that universities may be subject to a ‘misrecognition’ (Bernstein, 2000, p. 53). Misrecognition is when an institution, group or actor bases their actions on a narrow “functional analysis of what is taken to be the underlying features necessary” to “perform” (Bernstein, 2000, p. 53) or achieve a certain task or objective, i.e. ‘impact’, such that the analysis fails to recognise and take account of the complex sociocultural context. In the context of the impact agenda, for example, rather than *recognising* that the ‘impact’ of academic knowledge is grounded on universities having a relatively independent, autonomous and long-term critical approach to generating and transmitting knowledge, there is a risk that universities *misrecognise* impact as grounded on pure responsiveness to the immediate knowledge demands of certain actors. Again, my point is not a normative one which makes presumptions about what is and what is not legitimate or appropriate for universities. Rather, the point is merely to note the theoretical possibility that a bounded category can become so preoccupied with its external legitimacy, and thus so preoccupied with the perceived needs of ‘key’ external actors, that the bounded group (or the group associated with the bounded category) loses its distinctiveness and ceases to be the entity that it was.

‘Control’ over ‘boundary transactions’ is therefore a key factor in the potential reproduction of boundaries. I now move on to explore the concepts of ‘control’ and ‘boundary transaction’ in more detail.

### ‘Boundary transactions’ and ‘control’

Boundary transactions are interactions between a bounded group (or a group which identifies with some bounded category, in the way that physicists are identified with the bounded discipline of physics) and some other group beyond that boundary which may have an impact on that boundary. As discussed above, boundary transactions are unavoidable for the reproduction of boundaries. They are moments where the bounded group/category displays its value to other actors and thereby contributes to its legitimacy; in other words, they represent “the performances each system delivers for other systems” (Kantasalmi & Tuunainen, 2018, p. 354). But they also carry risks and “boundary maintenance issues” (Kantasalmi & Tuunainen, 2018, p. 354). This is because there is a trade-off between maximising the interests of certain external groups actors, in which case there is a risk that, over time, the bounded category may be seen by others as synonymous with that external group, as lacking autonomy, or as no longer having a distinctive identity, and, the other possibility, minimising boundary transactions, in which case there is a risk that the bounded category will appear distant and irrelevant by the majority.

In most cases, it can be expected that approaches to boundary transactions are unlikely to go in either direction to an extreme. This is because bounded categories are normally able to exert a certain amount of ‘control’ over the boundary transactions, and this control is an important part of the regulation of the relationship between the bounded category and wider society. ‘Control’, in the Bernsteinian (2000) sense, refers to control over the “legitimate forms” (p. 5) that interactions (or, more specifically, transactions) can take.

For example, any academic ‘output’, such as report of research, or a graduate, can be conceptualised as a transaction, since they bring something from within the academic boundary to a context beyond that boundary. But there are a range of different forms that such ‘outputs’ could take, and the form is influenced by the levels of control over the transaction by different actors. For example, research outputs published in academic journals and written in a highly technical form targeted at an audience with significant prior knowledge reflects that control over that output lay within the boundaries of academia. By contrast, a research output which took the form of, say, a workshop aimed at non-specialist practitioners or policymakers for whom certain aspects of the research may be useful (McNie et al., 2016) would imply greater control with the users of this research. To continue the other example of an ‘output’, that of a university graduate, where a student’s higher education consisted of strongly academic, discipline-specific training, this could be conceptualised as a transaction over which academia held significant control. By contrast, where curricula were designed to promote more “generic” skills (Bernstein, 2000, p. 53; see also Beck & Young, 2005, p. 189) such as employability, perhaps with input over aspects over the curriculum from some perceived key industrial sectors, this could be conceptualised as a transaction over which there was relative external control.

Control is therefore closely related to power. As Bernstein (2000) puts it, “[c]ontrol carries the boundary relations of power” (p. 5). The reproduction of boundaries, that is, the reproduction of the power of bounded categories, therefore depends in significant part on the relative control over boundary transactions. Reproduction depends on the boundary’s ability to regulate and control these transactions such that they reinforce the bounded category’s distinctive identity and distinctive value to wider society, or at least *certain* social groups, i.e. groups which are considered sufficiently powerful and relevant to the legitimacy of the bounded group/entity etc. in question. It is often the case that mechanisms are constructed for discriminating different types of external actor or group, depending on the relevance of the group for the boundary’s reproduction and on the risks that transactions with such a group might pose. Below, I draw from broader sociological, institutional and economic literature to elucidate some of these more nuanced features of boundary transactions.

As noted several times so far, transactions are essential and unavoidable. But transactions are ‘costly’, entailing ‘transaction costs’ (Muellerleile & Lewis, 2019; D. C. North, 1990; Tilly, 1998) D.C. North, 1990; Tilly, 1998). Transaction costs refer to the effort or “energy expended” in any “interchange” between actors (Tilly, 1998, p. 53). Transaction costs may be directly financial, but frequently this is not the case, with the ‘transactions’ requiring the mobilisation of emotional energy, social capital, or just the effort of learning about the needs, practices, assumptions and language/discursive practices of different groups of actors[[6]](#footnote-6).

In general, individuals, organisations and institutions prefer to minimise their transaction costs. There can be two elements to minimising transaction costs. One is to create close relationships so that communications and ‘transactions’ between certain actors becomes normalised, simplified, and relatively uncostly. Another is to reduce the frequency of interactions, particularly interactions with whom transacting is relatively costly. Transaction costs, then, are lowest under conditions of “[r]epeat dealing, cultural homogeneity (that is a common set of values), and a lack of third-party enforcement” (D. C. North, 1990, p. 34). Where these features are not met, actors are likely to have to “improvise” (Tilly, 1998, p. 56) this social interaction, which brings with it uncertainty and increased need for effort, monitoring and resources, in short, greater ‘costs’ (D. C. North, 1990; Tilly, 1998). The greater the demand and reward for certain transactions, the greater the incentive for universities to seek new ways to simplify and improve communications with, align values with, and formalise relationships with key transaction partners.

This perspective also sheds light on the importance of the construction of bounded entities in general. A bounded group institutionalises those features associated with low-cost transactions: repeat dealing, relatively shared values and culture, and relative autonomy mutually sustained by each individual’s collective belief in and contribution to the bounded group’s distinctive enterprise, i.e. the preservation, pursuits and transmission of academic knowledge. Under these low-cost interaction conditions, significant communicative efficiencies co-develop with a shared culture and identity through what Bernstein (2000) terms ‘restricted’ code. In his framework, ‘restricted code’ denotes the shortened forms of communication exhibited within a group of people who can take for granted a significant amount of shared prior knowledge and understanding. Examples could include communication between family members, or a religious ritual, or the communication in a specialist chemistry paper in which terminology and formulae can be used without further explanation, given the author’s assumptions about the expected readership. In all these cases, “the principle remains the same: meanings are symbolically condensed and conveyed through shared, tacit understandings. And *restricted* to those that know” (Moore, 2013, p. 66, original emphasis). By contrast, boundary-crossing often requires the use of ‘elaborating’ code (Bernstein, 2000). Elaborating code can best be understood as the extended and/or simplified terminology which characterises “the process of making the meaning available” (Moore, 2013, p. 67) to others not currently “in the know” (Moore, 2013, p. 68). Examples might include the explanation of concepts in a textbook or a classroom, or perhaps in reports of academic research to lay users. Any context where shared meaning is necessary to achieve a desired goal but where shared meaning does not yet exist might involve some instances of elaborating code. This would also include cases where shared meaning must be established for collaborative purposes, for example an interdisciplinary or academic-industry research collaboration, where either one or both parties may need to elaborate meaning to the other. In such cases, meaning “is elaborated in the absence of shared understandings: but *so that those understandings can become shared*. ...[W]e expand meanings (elaborating codes) in order for them to become condensed meanings ... (restricted codes)” (Moore, 2013, pp. 62-63, original emphasis).

The crucial issue of boundary transactions can be thought of in terms of a complex of trade-offs. Academics can attempt to restrict their transactions with those actors and groups which entail relatively fewer challenges, less contrast with academia’s values and objectives, in short, fewer costs and less risk to the legitimacy and reproduction of academic boundaries. But transactions are not entirely avoidable; attempts to minimise or restrict transactions and transaction costs in the above ways may, in the long run, result in academia failing to justify their boundaries. By contrast, though, being overly influenced by external interests and objectives may mean a reduction in distinctive identity and autonomy, and a weakening of boundaries. Preoccupation with ‘autonomy’ may lead to passivity when faced with external shifts and pressures, as opposed to a more engaged and proactive attempt to shape society and universities’ role within it (B. R. Clark, 1998). In Bernsteinian terms, whether ownership over the relevant category, say of academic science or a specific academic discipline, remains in the hands of the bounded group (those who are called ‘academic scientists’), or whether it comes to be ‘reshaped’ and ‘repurposed’ (Wright, 2016) by external groups, is ultimately a question of ‘power’, and this power is both reflected in, but also shaped by, the ‘control’ over boundary transactions.

From the perspective of the boundary lens adopted then, academia’s interest in transactions is to strike the balance between exercising and relinquishing control over transactions and power over the direction of its activities so that the result is the reproduction of its boundaries; by contrast, non-academic actors’ interest in transactions is the extraction of value from the bounded group. Although there is sometimes a reciprocity between these two goals, they are not necessarily equivalent. As such, boundary transactions *may* serve to reproduce a given boundary, but they may also, over time, act as mechanisms for the “weakening” (Henkel, 2004, p. 168) of boundaries. In Bernstein’s (2000) words: “control is double faced for it carries both the power of reproduction and the potential for its change” (p. 5). My study analyses this interplay.

### Differential power and control: institutional and disciplinary characteristics

So far, I have not discussed the heterogeneity of academia and the implications this can have for power and control, or for academic boundaries and the ways in which they are confronted and crossed in the course of academic research. Important dimensions of the heterogeneity of academia include the mission and prestige of institution and academic discipline. I will discuss these below.

Bernstein (2000) perceived many of the recent developments in academic knowledge and its production since the twentieth century in Europe, up to and including the impact agenda (albeit that Bernstein admittedly wrote before the RAE fully evolved into the impact-assessing REF, and before the term ‘impact agenda’ was in widespread use), in terms of a weakening of boundaries at the general level of academia as a system. From his perspective, academic disciplines, the universities which housed them, and the academic “field of production of knowledge” more generally, exhibited “strong insulation” in the nineteenth and early twentieth centuries; that is, they could exhibit a “unique identity” which was grounded on widely-accepted and socially legitimate authority over domains of knowledge, and which operated according to “its own specialised rules of internal relations” over which it had significant autonomy and insulation from external interference (Bernstein, 2000, pp. 5, 7, 9). At this time, academic knowledge producers had successfully “appropriated a space..., a specialised discrete discourse with its own intellectual field of texts, practices, rules of entry, examinations, licenses to practice, distribution of rewards and punishments... Organisationally and politically, ...[universities, and individual disciplines] construct[ed] strong boundary maintenance” (Bernstein, 2000, pp. 52, 54). Over time, however, the insulation of academic disciplines, both from each other and from wider society, weakened, at least in certain respects. In particular, increasing presence and power came to be afforded to more application-oriented research disciplines and inter-/multi-disciplinary fields, such as medicine, information science, architecture, business studies and engineering. These are more likely to be relatively “weakly bounded” and weakly insulated in that they “operate [at] ... the interface between the field of the production of knowledge and the field of practice”, indicating that the academic boundary in general “has become weaker” (Bernstein, 2000, pp. 9, 52, 99).

The emergence and growth of more application-oriented disciplines therefore have two lines of potential analytical implication. First, ‘applied’ disciplines can be compared empirically with ‘basic’ disciplines in terms of their experiences of confronting and crossing academic boundaries. There is evidence that differences do exist, for example, researchers in formal applied disciplines (i.e. engineering and materials science and metallurgy) spend on average approximately 1.5 times more time on external knowledge exchange than researchers in other STEMM disciplines (Hughes et al., 2016, p. 104). Second, the proliferation of applied fields and applied researchers may reflect a weakening of academic boundaries at a more fundamental level of academia-society relations. Again, there appears to be some evidence at least that institutional missions are genuinely shifting and impacting upon individual academics, as research has revealed a large increase in the proportion of academics who perceive “outreach” to be a key mission for their institutions (Hughes et al., 2016, p. 73). However, it is difficult to disentangle whether the rise of universities’ outreach mission (‘third’ mission) is predominantly a cause or effect of proliferation of applied researchers and applied disciplines – there are likely to be complex causal and reinforcing mechanisms operating in both ways. Although my research will not be able to offer statistical generalisations, it will address both of these lines of analysis, using disciplinary variation as a sampling criterion, and exploring the role of all sampled research, applied and basic, in terms of their implications for academic boundaries.

It is also important to consider another major dimension of academia, that is, differentiation across institutions. University league tables highlight differentiation of the sector at both global and national scales, with evidence that the UK has particularly strongly entrenched status hierarchies (Boliver, 2015). At the most research-intensive UK universities, academics spend on average over half of their work-time on research and less than a quarter on teaching; by contrast, ‘New’ universities established post-1992 spend only around a quarter of their time on research and over 40% on teaching (Hughes et al., 2016, p. 78). There is also a difference in the “research orientation” across UK universities, with Older universities conducting the greatest share of Basic research and Newer universities a greater share of Applied research (Hughes et al., 2016, p. 79). From Bernstein’s (2000) perspective, these data can be interpreted as indicating the power that ‘prestigious’ universities have to insulate themselves from “the *exigencies of the market*” (Bernstein, 2000, p. 60, original emphasis) and to define themselves by their close and bounded relation to transcendental knowledge – that is, through dominating the production of fundamental knowledge.

Another recent survey (Shields & Watermeyer, 2018) has found that academics’ perceptions of the underpinning “logics” or “shared rationalizations” (p. 2) vary quite significantly by type of university, predominantly by the level of research-intensity (having, incidentally, found little variation by discipline). While academics at research-intensive universities with significant research income perceived the underpinning logic of universities to be grounded on academic autonomy, those in less research-intensive universities perceived their own institutional logic to be beyond their immediate control, defined either in terms of “utilitarian” objectives derived from wider society, or else by a superior “managerial” authority, both of which counter the autonomy experienced at more research-intensive universities (Shields & Watermeyer, 2018, p. 8).

There is also likely to be some impact of these differences in terms of boundary transactions, although it is not simple to interpret this from available quantitative data. This shows that a greater proportion of academics at Newer universities than at Older universities are engaged in knowledge exchange with external organisations and believe that engagement with industry, business and the local community are important to career advancement and promotion, and they are proportionately more likely than academics at Older universities to be the initiators of their external interactions (Hughes et al., 2016, pp. 79, 123, 133). But it is academics at Older universities who appear better able to capitalise on the external value of their academic research, with greater percentages of patents, licensing of research outputs, spin-out companies, and research-based consultancies at Older universities than Newer, despite the apparently lower need for academics at Older universities to do these kinds of activities (Hughes et al., 2016, p. 80). A greater proportion of academics at Newer universities reported lacking the time, resources and skills to effectively interact with external organisations, and, in particular, they reported greater internal bureaucratic constraints (Hughes et al, 2016, p. 138). So, researchers at Newer universities spend more time on knowledge exchange and have greater apparent internal incentives to make interventions into the economy, and yet appear less successful than academics at Older universities on these measures – and this is also despite Newer universities being relatively more focused on ‘applied’ research than Older universities (Hughes et al., 2016, p. 124). Again, the causal links are difficult to disentangle, but these data fit a picture of a distinction between less prestigious institutions undergoing relatively greater struggles to contribute to objectives and interests beyond academic boundaries, and more prestigious institutions able to focus relatively more on internally-generated objectives (i.e. the ‘transcendental’) while, somewhat paradoxically, facing relatively fewer difficulties with external engagement and revenue-generating activities.

My working interpretation of these data, when considered through the ‘boundary’ lens, is that: (i) they reflect a hierarchy whereby more prestigious institutions are relatively more insulated, such that its staff can afford relatively greater focus on those core internal objectives and criteria that make academia distinctive and which give meaning to its boundaries; (ii) prestige appears to be linked to the strength of relation to the transcendental; (iii) relatively less prestigious institutions appear relatively less well insulated, and, to borrow a phrase from one of Bernstein’s intellectual collaborators, are relatively more “exposed to the need to communicate with outsiders” (Douglas, 1996, p. 55) and therefore more oriented towards external outreach and engagement; (iv) but, conversely, despite the efforts of researchers at less prestigious institutions, they seem to face a greater level and range of challenges in crossing these boundaries. My own research will be able to take a more qualitative look at these issues.

## Forms of boundary transaction: a literature review

In this section I draw out five main forms of boundary transaction that I have identified from social science literature on academic research. These are ‘outreach’, ‘collaboration’, ‘use-focused outputs’, ‘boundary structures’ and ‘boundary-spanning’. Each form of transaction brings something of the academic into a non-academic context (and/or vice versa). For each form of transaction, I highlight links between the relevant literature and the ‘boundary lens’ I have adopted. I also discuss how each form of transaction involves both challenges to, but also the potential for, the reproduction of academic boundaries.

### Outreach: new networks and activities for the university’s ‘third mission’

Outreach refers to participation in and generation of networks with potential users, beneficiaries and stakeholders. Although outreach can be understood as a key form of boundary transaction in itself, a major motivation for outreach is to develop opportunities for other forms of transaction.

Outreach came to the fore as the core element of the imperative towards a ‘third mission’ for universities (Vakkuri, 2004). According to several commentators (Benneworth & Charles, 2013; Jongbloed, Enders, & Salerno, 2008; Sánchez-Barrioluengo, 2015; Zomer & Benneworth, 2011), the origin of the articulation of a ‘third mission’ for universities lies in the work of the Organisation for Economic Co-operation and Development (OECD), Centre for Educational Research and Innovation (CERI), in particular a CERI (1982) report on the role of universities in supporting their ‘community’ and ‘environment’, broadly defined (see pp. 65-66). Starting with increased attention to outreach and network-building, universities were to extend their “public service function” (CERI, 1982, p. 10). Outreach would allow universities to ‘tap into’ the needs and demands of potential users, and to generate the networks and relationships necessary for enabling effective dissemination and application of academic research. The ‘third mission’ eventually came to include a wide range of “activities involving the generation, use, application and exploitation of knowledge and other university capabilities outside academic environments” (Koryakina et al., 2015, p. 63; see also Cervantes, 2017; May & Perry, 2013a). But in its simplest and most essential form, the core objective of the third mission from the perspective of universities’ research function was outreach (Etzkowitz et al., 2008; Sataøen, 2018; Vakkuri, 2004).

As Vakkuri’s (2004) research showed, this “outreach” imperative was not only something “imposed on universities” externally, but also something which was generated by universities themselves, what he calls a “*boundary enactment transaction*” (p. 294, emphasis added). This concept of ‘enactment’ through boundary transactions comes from institutional theory (Dimaggio & Powell, 1983; J. W. Meyer, 1977; J. W. Meyer & Rowan, 1977; D. C. North, 1990). From this perspective, outreach activities and initiatives can be understood as not only responses to their environment but also ‘enactments’ which impact upon and change that environment (whether deliberately or not) (Vakkuri, 2004). In other words, universities’ boundary transactions *enact* the environment in which universities operate. Indeed, the CERI (1982) report is itself the result of boundary enactment – the new imperatives proposed in this report did not emerge independently of universities’ activities and strategies, but rather was itself inspired by the ‘outreach’ activities that a few European universities were already experimenting with in the hope of generating local economic benefits and attracting financial support from new potential sponsors. From this perspective, the demand for increased ‘outreach’ and, ultimately, ‘impact’, is partly the result of the successful ‘enactment’ efforts on the part of (some) universities seeking to raise their esteem, valuation and legitimacy in the eyes of wider society.

Research has shown how ‘boundary enactment’ is not merely an accidental outcome or by-product of outreach but can also be a deliberate goal. For example, in a case study of one university, it was found that academics’ outreach activities aim to “mobilize ... interest in their research” (Benneworth, De Boer, & Jongbloed, 2015, p. 288) and improve their opportunities of winning funding bids. Similarly, when given the opportunity to contribute to government information-gathering and policymaking, academics saw this not only as an opportunity to disinterestedly pass on their expert insights, but to “leverage ... their own specific knowledge … into a political arena” (Benneworth et al., 2015, p. 288). This chimes with findings from Knorr-Cetina’s (1983) studies, which show how scientists attempt to influence and to account for the interests of a broad range of actors, including grant agencies, industry representatives, and other potential users and stakeholders, in order to advance their own research. Such “transepistemic relations” (Knorr-Cetina, 1983, p. 132) lead researchers to reach out beyond the “boundaries of a scientific community” (Knorr-Cetina, pp. 132-133). Outreach is therefore not only about transmitting knowledge to potential users, but about bringing academics into a boundary-crossing “dialogical space” (2011) where they “negotiate the social demand for particular types of scientific knowledge, contest political and economic constraints on their research agenda or challenge illegitimate uses of their research” (S. Smith et al., 2011, p. 1377).

However, this does not mean that all academics are necessarily entirely comfortable or sanguine about the demands and opportunities of outreach, particularly given the way outreach and engagement are framed in the context of the impact agenda. For example, recent research at the level of individual academics has revealed tensions between the system-level impact agenda on the one hand, with its basis in the third mission and ‘academic capitalism’, and the individual-level motivation for engagement and outreach on the other, often grounded in a sense of “epistemic responsibility” (Chubb, 2017, p. 2). Moreover, there are multiple instances of academics reflecting on what the impact agenda means for their own field of research (for example, Evans, 2016; Holland, 2015; Kellard & Śliwa, 2016; Laing et al., 2018; MacIntosh et al., 2017; Marcella, Lockerbie, & Bloice, 2016; Moreno-Casbas, 2016; O’Connell, 2018; K. E. Smith & Stewart, 2017; Wimmer, Rethlefsen, Jarvis, & Shipman, 2016). While these papers are by no means entirely critical of the impact agenda, they display significant concerns about the details and implications of impact policy and assessment.

Outreach, then, is one of the main forms of ‘boundary transaction’, and it is a central goal of the ‘third mission’ and the ‘impact agenda’ to promote such transactions. As a boundary transaction, outreach is a potential mechanism for the potential reshaping or reproduction, maintenance or weakening, insulation or openness, of academic boundaries. Different perspectives or different outreach conditions may provide different interpretations. For example, on the one hand, academic boundaries may be reinforced to the extent that outreach enables academics to extend and consummate their research in the form of non-academic impacts. But the pressure to ‘reach out’ and generate opportunities for impact ever more frequently and intensively may have detrimental effects on other of academia’s values, virtues and goals.

### Collaboration: knowledge exchange and the ‘new’ epistemologies of academic science

While ‘outreach’ referred to the general imperative facing academics to extend the reach of their networks and links to potential users, ‘collaboration’ focuses on what is probably a more pressing matter for the question of academic boundaries. That is, the relationship between academic research and the knowledge activities of non-academic knowledge intensive sectors, primarily in industries such as advanced manufacturing, biotechnology and computing.

Some express concern about an age of “postacademic science” (Ziman, 1996a, p. 67) where there is no discernible distinction between the knowledge functions of academic research and those of industry. Even if this seems premature, it is important to acknowledge that there is evidence of increasing interdependence between academia and other knowledge-intensive institutions and sectors, particularly in STEMM fields. Concerns about ‘postacademic science’ stem from the emergence of so-called ‘Mode 2’ knowledge production conditions (Gibbons et al., 1994; Ziman, 1996a). ‘Mode 1’ refers to ‘traditional’ forms and organisation of academic knowledge production, with a primary focus on basic knowledge in distinct disciplines, with only occasional cause for scientists to think about the implications of their research for other disciplines or for practical use (Gibbons et al., 1994). Later sections will discuss the ‘transdisciplinary’ nature of Mode 2 research. For now, I want to focus on the emphasis Mode 2 places on the *context of application*. This is not only a question of scientific topic or selection of a research agenda, although these are also at stake. Rather, the increased focus on contexts of application has potential implications at the heart of academic science. Under Mode 2, it is no longer sufficient that epistemologies be scientifically “*reliable*...; knowledge also needs to be *‘socially robust’*, because its validity is no longer determined solely, or predominantly, by narrowly circumscribed scientific communities, but by much wider communities of engagement comprising knowledge producers, disseminators, traders, and users” (Nowotny et al., 2003, pp. 191-192, emphasis added).

Interview-based studies have researched how STEMM academics are experiencing and responding to an increasingly market-oriented academic research system, with a focus on changing epistemic goals and values, and the tensions associated with the need to generate revenue whilst also staying true to the educational and public missions of universities (Cantwell, 2015; Slaughter & Leslie, 1997). Their findings highlight (i) that academics experience significant pressure “to demonstrate excellence in two research ventures, fundamental *and* commercial” (Slaughter & Leslie, 1997, p. 20, original emphasis), (ii) that these pressures can “persuade some faculty members to change the focus of their laboratories” (Cantwell, 2015, p. 495) towards projects aimed at maximising revenue-generation rather than fundamental learning, and (iii) that the strategies and practices established under these conditions involve a “micro-level” (Cantwell, 2015, p. 488) complex of inputs and outputs which integrate knowledge, people and technologies in new ways which reshape the system from the bottom-up in the likeness of a commercial setting. These are the conditions of a relatively new ‘academic capitalist’ system, whose content, epistemologies and values, at least in STEMM fields, are blurring with those of industrial science. That is, there is a “blurring” (Henkel, 2004, p. 180) of academic and non-academic boundaries.

Other research has been able to go into even greater depth in analysing shifts in the epistemic content of specific academic fields. One example is Hoffman’s (2011) ethnographic and interview-based research in a US university computer science department. He found that some academic scientists’ consideration of users did not merely mean shifting the topics of study or soliciting the needs of users to ensure outputs were relevant and usable, but became intertwined with epistemology. These academic researchers, Hoffman (2011) argued, “believed that knowing a lot about users was *the* central pillar of scientific discovery” (p. 453, original emphasis). In another example, identified by W.C. Clark et al. (2011), scientists were forced to rethink and adjust their epistemology when co-producing knowledge with agriculture practitioners. One of the main points of incompatibility causing this re-think was the different conceptions, perceptions and implications of “uncertainty” estimates (W.C. Clark et al., 2011, p. 4621) held by scientists and practitioners. What counts as a reasonable amount of uncertainty, how different levels of uncertainty affect the knowledge claims that can be made, and how to proceed having ascertained the level of uncertainty, all can be understood differently by scientists and practitioners (McNie et al., 2016). To take an example from the humanities, Ylijoki (2003) also identified epistemological shifts amongst historians interviewed in her study of changing values and practices in the context of academic capitalism. This was prompted by funding bodies increasingly favouring big projects which require increasingly “collective-, project-oriented research” (Ylijoki, 2003, p. 314). While this might at first seem only to require a shift in organisational practice, collaboration in fact has potentially significant implications for the “nature of knowledge” (Papatsiba, 2013b, p. 443), particularly in a humanities discipline like history, where “the personal impact of the researcher is regarded as an essential element in the knowledge production process” (Ylijoki, 2003, p. 315). Shared responsibility over the epistemic content of research requires a greater need for more objective and codified rules which, while they permit disparate collaborators, could limit the potential for novel individual interpretations that has traditionally been a central epistemological feature of humanities disciplines. In this way, “historians have succeeded in accommodating the[se] external pressures quite successfully to their own traditions, values and ideals” (Ylijoki, 2003, p. 314), as has more frequently been found in STEMM fields.

Thanks to this blurring of boundaries and interdependence between academic and non-academic forms of knowledge production, research in the innovation literature has come to conceptualise academic and industrial/entrepreneurial knowledge “as overlapping and interacting systems, with the former augmenting the capacity of the latter to solve an increasing range of complex problems” (Pavitt, 1998, p. 796). In the context of a knowledge-based economy, this places universities at the centre of a ‘triple helix’ of government-academia-industry relations driving innovation and economic growth (Etzkowitz & Leydesdorff, 1995; Leydesdorff & Etzkowitz, 2001).

As with outreach, academic researchers’ collaborations and interdependencies with non-academic institutions and sectors, conceptualised as a form of ‘boundary transaction’, has the potential to operate as a mechanism for both the reproduction and weakening of academic boundaries.

### Use-oriented outputs (‘boundary objects’)

As well as outreach and collaboration, the outputs of academic research themselves can be conceptualised as having a boundary-transacting function. Outputs can be thought of as ‘boundary objects’ (Star & Griesemer, 1989), that is, objects which provide value and meaning to actors or groups either side of a boundary. Before moving onto relevant empirical examples from the literature, it is helpful to contextualise the concept of boundary objects within the theoretical lens of ‘boundary work’ or ‘boundary management’ (W. C. Clark et al., 2016; McNie et al., 2016; Star & Griesemer, 1989)

‘Boundary work’ refers to the efforts, activities and products that go into constructing and managing “the interfaces among various stakeholders engaged in harnessing knowledge” (W. C. Clark et al., 2016, p. 4615) for a particular purpose. Not all forms of boundary transaction necessarily require significant ‘boundary management’ (McNie et al., 2016, p. 890) and, therefore, ‘boundary work’. But where significant collaboration between actors across boundaries is required, it is often the case that boundary work is important for allowing “meaningful participation” (W. C. Clark et al., 2016, p. 4615) for all concerned. Examples of boundary work could relate to the construction of mechanisms and opportunities for jointly setting agendas, plans of action and criteria for evaluation of collaborative activities and projects, say in the context of a university-industry partnership. Some such forms of boundary work will be relevant under the following sub-section (‘Structures’). Pertinent here is another form of boundary work, that is, the production and circulation of ‘boundary objects’.

Academic boundary objects are those that can carry or promote boundary transactions (Sataøen, 2018). For example, they might enable direct collaboration or other form of interaction, or alternatively, the object might itself constitute a form of communication such that two (or more) distinct and bounded groups jointly find meaning in the objects in a way that enables each to advance their own objectives and interests. Examples found in my own sample include “reports, models ... or standards” (W. C. Clark et al., 2016, p. 4615) based on scientific knowledge, provided these can be used to promote transactions across academic boundaries with potential users of or stakeholders in the relevant knowledge. For instance, a scientific paper adopting what in Bernsteinian theory is termed a ‘restricted code’ (Bernstein, 2000, p. 183; Moore, 2013, p. 583), full of specialist, esoteric language and symbols and targeted at similarly-trained experts, would be unlikely to be regarded as a boundary object. By contrast a paper published in a user-focused form and adopting ‘elaborated’ or ‘elaborating code’ (Bernstein, 2000, p. 183; Moore, 2013, p. 67), with all key technical terms and concepts sufficiently explained so that their relevance for user groups and other non-scientific stakeholders was made clear, could be understood as a boundary object. So too could specifications of guidelines which, although based on rigorous underpinning scientific research and theory, are presented according to technical standards of relevant professional practitioners rather than only academic scientists. Technologies may also be boundary objects, for example the life sciences are increasingly driven by advances in instrumentation, software and other technologies, some of which can function as a ‘boundary object’ in that they prove to be valuable to, say, social scientists or industry (Nowotny, 2005).

Boundary objects may be produced either in collaboration with two actors/groups either side of a boundary, or they might be produced by actors/groups on only one side of the boundary. The key point is that the objects “are both adaptable to different viewpoints and robust enough to *maintain identity across them*” (Star & Griesemer, 1989, p. 387, emphasis added).

Providing a valuable empirical analysis of such boundary objects, Slaughter et al. (2004) conducted interviews with senior academic scientists about their outputs to ascertain their perceptions about “boundaries between academe and industry”, about the “boundary maintenance and disputes ... encounter[ed]” and about the “quandaries ... face[d] as they negotiate these new boundaries” (p. 132). The authors found that potential boundary objects could be sources of dispute, and that it may take time before different parties come to perceive certain products as mutually beneficial, and only when this occurred did they take on the character of boundary objects, in the above sense. The main objects or products at issue were those of publications and patents. Disputes arose where publications were perceived by industry to have no relevance to their goals or where patents were seen by academics purely as a means to own and commodify knowledge. However, where industry came to see publications as part of the essential process of advancing knowledge from which they could draw, and even aimed to collaborate in academic research and co-author publications as a way to contribute to and shape this process and to increase the knowledge base of the company, these publications could come to operate as boundary objects (Slaughter et al., 2004). Similarly, where academics came to see patents as part of a process whereby a business model based on intellectual property could yield benefits to the academic’s own ‘core’ missions, i.e. their own research agenda, students, and institutions, as well as yielding benefits to wider society in the long term, patents too could operate as boundary objects (Slaughter et al., 2004).

Boundary work, particularly the production and circulation of knowledge-based boundary objects, such as I have been discussing above, incurs “non-trivial ... transaction costs” (Hoffman, 2011, pp. 446-447). At a minimum, this involves the academic scientists learning new discursive and cultural practices which are more aligned with the relevant non-academic actor or group, most commonly industry in the case of STEMM research. Despite the challenges, this may be welcomed, as research has identified some STEMM academics who believe that the “best science results from an iterative process that tacks back and forth between user needs, research design and scientific inquiry” (Hoffman, 2011, p. 454). But, occasionally, the costs may be greater and cut more fundamentally to the heart of “sacred” (Bernstein, 2000, p. 10; Slaughter, Campbell, Holleman, & Morgan, 2002, p. 304) values around the content and results of academic science. In some cases, research outputs may omit results if they are perceived to be of commercial value to a sponsor, partner, or sometimes even an academic him/herself (Slaughter et al., 2004; Slaughter et al., 2002; Slaughter & Rhoades, 2010).

The impact agenda and related policy agendas are likely to increase the pressure to generate such outputs as those leading to the above boundary tensions. Research on academics who participate in competitive markets, whether for revenue or for position-taking in manufactured markets such as those constructed by the REF, has revealed “complicity of a neoliberal attitude of success at any cost” (Chubb & Watermeyer, 2017, p. 2363). An alternative analysis might portray universities as occupying a subservient role in the context of a ‘technoscientific’ social order (Latour, 1987, p. 162; Leydesdorff, 2012, p. 32; Slaughter et al., 2002, p. 286; Ziman, 1996b, p. 313) in which powerful political, commercial and military interest groups aim to “control” (Bensaude-Vincent, Loeve, Nordmann, & Schwarz, 2011, p. 366) and “construct” (Schmidt, 2011, p. 104) the social world via technological projects which universities must contribute to in order to survive (see Kantasalmi & Tuunainen, 2018, pp. 348-352 for a case study). Either way, the heavy ‘transaction costs’ identified in some cases have resulted in calls for greater “insulation ... [and] shelter from external pressures” (May & Perry, 2013a, p. 206) so that the need to focus attention on such outputs can be reduced.

My own analysis will examine the role of boundary-transacting research outputs in the sampled bodies of STEMM research. Analysis of such outputs and the value they provide in terms of both non-academic impact and the advancement of the academic mission will feed into my broader analysis of the power and control over academic boundaries and STEMM research.

### Boundary structures

A range of “boundary structures” (Chau, Gilman, & Serbanica, 2017, p. 200) or “boundary organization[s]” (Guston, 1999, p. 88) have been identified which serve to link universities to collaborators, users, beneficiaries and markets. Boundary structures have long been recognised as important for universities’ third mission. CERI (1982) highlighted favourably examples of what they refer to as “horizontal or transversal structures” (p. 43), arguably the first form of which were “the so-called science shops in The Netherlands in the 1970s ... [which] linked university researchers to civil society organisations in a broader attempt to democratize both science and society” (Taheri & van Geenhuizen, 2016, p. 32). Regional ‘university centers’, such as found in Finland, continue this explicit third mission goal, partnering with other organisations to bring certain academic activities and offerings to regions without a university (Vakkuri, 2004, p. 301; see also Lähteenmäki-Smith, 2014; Variainen & Viiri, 2005). Other sociological studies of universities have revealed the “outward-facing centres” (B. R. Clark, 1998, p. 6) driving the ‘entrepreneurial university’, and the “interstitial” or “intermediate” organisations (Slaughter & Rhoades, 2010, p. 1) which are “key elements ... of academic capitalism ... blur[ring] the boundaries between markets, state, and universities” (Kaidesoja & Kauppinen, 2014, p. 178).

Boundary structures linking universities to markets, such as technology or knowledge transfer offices, science parks, and incubators to support academic spin-out companies, have attracted most attention in the literature (Chau et al., 2017). They support the kinds of ‘collaboration’ and ‘outputs’ already discussed above. Therefore, I discuss here another kind of boundary structure, one which has potentially more fundamental consequences for academic research activity in that they compete with traditional departments as a “major way to group academic work” (B. R. Clark, 1998, p. 6; see also Ponomariov & Boardman, 2010), namely, problem-centred research centres. The traditional form of co-ordination of academics has been according to distinct academic disciplines. By contrast, these problem-oriented research centres operate as interdisciplinary, transdisciplinary, or even post-disciplinary units, linking academia to society in the sense that they co-ordinate academic researchers according to their potential relevance to solving external, non-academic problems, such as the development of ‘greener’ industrial processes, reducing the human impact on natural life and environments, and using technology to maximise the clinical use of inpatient data (to take a few examples from my research studied in this thesis).

With the rise of ‘mode 2’ forms of knowledge production (Gibbons et al., 1994) in the context of ‘academic capitalist’ (Slaughter & Rhoades, 2010) and ‘neoliberal’ (Olssen, 2011; Watermeyer & Olssen, 2016) systems of higher education and academic research, disciplinarity as a mode of integrating researchers and advancing knowledge has been under great scrutiny. This goes back some decades, with the aforementioned CERI (1982) report describing disciplines as not only “scientific realities but also social institutions which define a sharing of knowledge or of power” (p. 137). For B. R. Clark (2008):

“Disciplines have conscious goals. In fact it is their intentions and strivings and not those stated as the broad aims of higher education which determine the real goals of the many departments, schools, and sub-colleges that make up the operating levels of universities” (p. 285).

To counter this, inter- or transdisciplinarity is seen as a solution to problems of the relations not only between bodies of knowledge, but between science and society more generally (Barry & Born, 2013). New research units grounded upon “ideas of interdisciplinarity and transdisciplinarity” aim to promote “boundary transgressions, in which the disciplinary and disciplining rules, trainings and subjectivities given by existing knowledge corpuses are put aside or superseded” (Barry et al., 2008, p. 21). Transdisciplinarity in particular implies a “transcendence of disciplinary norms ... in the pursuit of ... real-world problem-solving, or ... overcoming the distance between specialized and lay knowledges” (Barry et al., 2008, p. 27). As such, it “does not respect institutional boundaries” (Nowotny, 2006, p. 2). It is practical problems generated beyond academic boundaries, rather than disciplinary ones generated within academic boundaries, that are the main driver and basis for coordination of academic effort and expertise (Nowotny et al., 2003). In this context, new forms of academic organisational structure are likely to be “created on the basis of demands from society more than internal institutionalized norms such as professional or disciplinary” (Nyhagen & Baschung, 2013, pp. 410-411).

From Bernstein’s (2000) perspective, these developments reflect a “weakening” of boundaries and “greater external dependency” (p. 52). However, boundary structures, in facilitating boundary transactions, may also have a role in reinforcing and reproducing certain aspects of academic boundaries. For example, transdisciplinarity, rather than implying or leading to “*postdisciplinarity*” (Bhaskar, 2010, p. 5, original emphasis), often assumes and requires *disciplinary* expertise and knowledge from which to draw. And to that extent, it arguably provides support for a continuation of at least some aspects of academia’s traditional shape, for example an education based on boundaries between disciplines *and* between disciplinary and non-disciplinary concerns. Moreover, from the perspective of the university’s “ideal” to comprise “a totality or even the totality of the branches of human learning” (Durkheim, 2013, p. 93), any novel insights attained by transdisciplinary structures may be interpreted as in keeping with, rather than necessary challenging, ‘traditional’ academic objectives. Furthermore, if the universities’ students are able to learn through or from such boundary structures, this may support universities’ other mission, that is, their duty towards the education, enrichment and employability of students. Indeed, historically, it has been a key feature of the university’s development that the work of academics can simultaneously contribute to their own research and careers, the advancement of knowledge, the education, training and life-chances of others (students), and to the needs of a whole range of non-academic groups, and that these different functions can sometimes be synergistic (Ben-David, 1971, 1977; B. R. Clark, 1989, 1995; Perkin, 1984).

Despite the UK impact agenda’s outward promotion of interdisciplinarity (Bessant & Robinson, 2019; Wilsdon et al., 2016), and even evidence that interdisciplinarity generates impact more effectively (King’s College London & Digital Science, 2015), the actual response to the impact agenda highlights the challenges and barriers faced by those wish to see academia fully ‘transcending’ its disciplinary boundaries. The impact agenda’s ‘neoliberal’ (Olssen, 2011; Watermeyer & Olssen, 2016) demand for ‘accountability’ and construction of markets in which departments compete with each other on local (i.e. with neighbouring departments in the same university) and national (i.e. with equivalent departments in different universities) fronts, forces universities to articulate “formal clearcut boundaries” (Vakkuri, 2004, p. 304). This, ironically, “encourages boundary management both within and across disciplines” (Hellstrom & Jacob, 2000, p. 72), tending to reinforce rather than loosen disciplinary boundaries. Further evidence of this can be seen in the way in which many academics have reflected on and attempted to respond to the impact agenda. In fields as diverse as mathematics (Meagher & Martin, 2017), information science (Marcella, Lockerbie, & Bloice, 2016), public health (Evans, 2016; Greenhalgh, Jackson, Shaw & Janamian, 2016), nursing (Moreno-Casbas, 2016; Wimmer, Rethlefsen, Jarvis, & Shipman, 2016), business and management (Kellard & Śliwa, 2016), policy studies (Holland, 2015; K. E. Smith & Steward, 2017), geography (P. North, 2013) and education (Laing, Mazzoli Smith, & Todd, 2018; O’Connell, 2018; Papatsiba & Cohen, 2019), academics have responded to the impact agenda in the way that seems most natural to them – that is, from their own disciplinary perspectives.

It is therefore possible that boundary transactions promoted by the impact agenda and similar policy agendas and developments has the ambiguous and somewhat paradoxical result of, on the one hand, promoting boundary transaction structures, but at the same time presenting a new opportunity for position-taking amongst disciplines, who feel pressured to reassert their distinct identities and ownership over distinct knowledge domains.

Again, B. R. Clark (2008) appears to capture the dynamic when he writes:

“The disciplinary imperative may well [still] be *the* driving force in modern higher education. But it is powerfully shaped in turn by the imperatives of the institutional sectors and the large structures of incentive and reward that characterize the national settings.” (p. 287)

My own analysis will seek out all boundary transaction structures associated with my sampled BoRs, including those associated with new, transdisciplinary forms of co-ordinating researchers as well as those directly connecting to the market. While new structures inevitably alter institutional shape to some extent, my interest is in the impact that such structures and their associated transactions have on the overall strength of academic boundaries.

### Boundary-spanners

I have already discussed how boundary transactions may be enacted through the (co-)production of ‘boundary objects’, primarily in the form of written or technological outputs and outcomes of research. One of the restrictive features of boundary objects is that they are relatively fixed. Although they can be open to different interpretations, and this is an essential feature of their effectiveness, the shared knowledge and meaning codified within an object is, by its nature, relatively inflexible. But, as shown by chemist and philosopher Michael Polanyi (1962), much knowledge is ‘tacit’ and not easily transferred through codified objects. As such, any attempt to “modify” knowledge or “meaning”, say in the process of translating or applying academic knowledge to contexts of application, is, at root, “a tacit..., heuristic feat”, and therefore also distinctly “personal” (Polanyi, 1998, p. 111). Indeed, research in the innovation and economic literature suggests that “the main practical benefits of academic research” are not the research outputs, per se, but rather the “tacit (i.e., non-codifiable) knowledge through personal mobility and face-to-face interaction” (Pavitt, 1998, p. 797; see also Lam, 2007). Moreover, the more tacit is the knowledge, the greater the need for strong social ties and “frequent contacts” (Sousa-Ginel, Franco-Leal, & Camelo-Ordaz, 2017, p. 1138).

All this puts a premium on so-called “boundary-spanning” individuals (Taheri & van Geenhuizen, 2016, p. 32). ‘Boundary spanners’, also referred to as knowledge “brokers” (Contandriopoulos, Lemire, Denis, & Tremblay, 2010, p. 464; M. Meyer, 2010, p. 118), “work at the boundaries” (Chau et al., 2017, p. 205) of academia to “impart tacit as well as codified knowledge to other stakeholders” (Youtie & Shapira, 2008, p. 1202). They carry scientific expertise into various contexts of application, either applying knowledge and solving problems directly, or else transferring or ‘brokering’ knowledge transactions by taking up roles that ‘span’ two or more sites of knowledge production, development and application.

Boundary spanners are therefore of increasing importance to universities and non-academic knowledge-intensive sectors, primarily industry, (Henkel, 2004; Hoffman, 2011; M. Meyer, 2010; Vakkuri, 2004) and are a key mechanism through which several of the boundary transactions discussed in earlier sub-sections of this chapter are performed and enacted. They include, for example, those academics who draw upon brief spells in industry to generate networks and research agendas in collaboration with users and sponsors; those industry or other non-academic scientists who take on honorary or temporary academic posts in specific collaborative configurations; and those who create academic spin-out companies to patent and commercialise their research-based technologies (Brennan et al., 2016). Etzkowitz & Viale (2010) classify these under the term “polyvalent roles”, in line with their focus on the “polyvalence” of knowledge (pp. 596, 606). However, potentially more fundamental from the perspective of universities as higher education institutions, is the role that students can play in academia’s boundary-spanning and boundary transactions. It is this that I will focus on for the remainder of this sub-section.

Evidence from across Europe and the English-speaking world suggests the greatest ‘return’ from investment in STEMM education and research is the output of human capital in the form of skilled individuals, especially when also trained in research (B. R. Clark, 1995; Coad et al., 2014; Diamond et al., 2014; Frontier Economics, 2014; Hughes & Kitson, 2012; Hughes & Martin, 2012; Pavitt, 1998; Reid, 2014; Salter et al., 2000; Slaughter et al., 2002; Zellner, 2002). That “students represent an important potential resource” (CERI, 1982, p. 74) for advancing universities’ third mission goals has long been acknowledged. Most STEMM students do not go onto academic careers – even at the level of STEMM PhD graduates, the majority exit academia and predominantly work in knowledge-intensive areas of scientific application (Royal Society, 2010). This means that academic researchers who are involved in STEMM higher education, particularly the training of doctoral students, are likely to have significant personal connections with individuals in a range of knowledge-intensive organisations who represent potential collaborators, users and even sponsors of academic research. In their analysis of such boundary transactions, Slaughter et al. (2002) find graduate students to be analytically akin to “tokens of exchange” (p. 305):

“Former students employed by large corporations sometimes continued their involvement with their professors and departments by serving as consulting faculty members and visiting university labs as frequently as once a week, allowing the former students to keep current on research and identify future employees... Former students frequently sat on university or college industrial advisory boards and sometimes in that capacity assisted in designing new graduate courses... When professors wrote proposals to industry, they listed the graduates presently working at the company to show a nondeliverable benefit to the corporation that was valued as highly as any research...” (Slaughter et al., 2002, p. 305).

Of course, STEMM students and graduates can often play a more active rather than merely passive boundary-spanning role. For example, research has revealed doctoral students managing their own boundary-spanning career trajectory and research profile by “*exporting* parts of their academic science to industry while simultaneously *importing* commercially-derived practices to the lab” (Hoffman, 2011, p. 50, emphasis added). Research into the experience of doctoral students involved in joint industry-academia doctoral study goes into greater depth about the interplay of structure and agency and the conditions for effective doctoral education and boundary-spanning. While such programmes can offer value to all parties in some cases, in other cases, the student is prevented from playing this role effectively, for example due to unequal investment in the student and their project from the industrial or academic side; disagreements (amongst potentially all three parties) over appropriate topics; a lack of staff time being allocated to the dedicated education and training of the student, particularly occurring where the doctoral supervisor also had a joint academic and industry role, thereby suggesting that boundary-spanners may not be best-placed to train future boundary-spanners (Mendoza, 2007; Wallgren & Dahlgren, 2007).

Nonetheless, the evidence supports the view that demand amongst knowledge-intensive sectors for academic research knowledge is both enabled by and reinforces the university’s key distinctive feature, that is the “flow-through of human capital” (Etzkowitz, 2008, p. 1) in the form of students. Quantitative analysis on the relationship between US academics, students and industry shows convincingly that students “constitute a bridging component in the establishment, maintenance and expansion of university-industry collaborations” (Ponomariov, 2009, p. 61). However, it also puts new pressures upon universities. For example, the increased prominence of boundary-spanning roles of graduates has prompted shifts in higher education curricula, including at doctoral level, towards more ‘generic’ skills rather than focused solely on disciplinary training (Adkins, 2009; Hancock, Hughes, & Walsh, 2017; Hancock & Walsh, 2014; Henkel, 2004; Mendoza, 2007; Thune, 2010), as students are having “entrepreneurial” (Papatsiba, 2013a, p. 58) identities imposed upon them by national and supranational policy agendas. While some see this as an important and legitimate goal of doctoral education given the reality that most doctoral graduates leave academia (Hancock, Hughes & Walsh, 2017; Hancock & Walsh, 2014), critics argue that such ‘genericism’ could diminish the distinctive scientific value of higher education and, therefore, have a perverse effect on the stock of human knowledge and the criticality and innovativeness of graduates (Beck & Young, 2005; Young, 2008).

The role of boundary-spanners therefore throws up several of the same issues and tensions of other of the forms of boundary transactions discussed above. But these are heightened when students come to take on the role of (potential) boundary-spanners and the effects of research-related boundary transactions come to impact upon the university’s teaching mission.

## Boundary transactions in context: the multi-dimensionality of research

### The complexity of research and research knowledge

Research is complex and “multi-dimensional” (McNie et al. 2016, p. 885). At root, this complexity is derived from the “polyvalence” of knowledge (Etzkowitz & Viale, 2010, p. 596). Research knowledge does not belong only to the individual or organisational context in which it is generated, and it can be conceptualised in terms of both its theoretical and potential practical relevance (however distant either of these may first appear) (Brennan et al., 2016); knowledge generated in one discipline or context can have meaning and relevance elsewhere; knowledge can have multiple outputs and forms, and can be more-or-less codified, but this often changes and potentially reduces the richness of ‘tacit’ knowledge (Donovan & Hanney, 2011; Etzkowitz & Viale, 2010; McNie et al., 2016). The complexity of the research process is only heightened when attempting to fully capture the interdependence between the context of knowledge production and wider society (Reed et al., 2018; Simon & Schiemer, 2015). And this multi-dimensional complexity is reflected in the structural organisation of universities (Gumport & Snydman, 2002), as evidenced by the proliferation of novel ‘boundary structures’ discussed above, associated with the ‘entrepreneurial’ university (B. R. Clark, 2004a; Etzkowitz, 2013).

McNie et al. (2016) are interested in specifying the multiple elements of this complex multi-dimensionality, and particularly doing so in a way which acknowledges the sometimes subtle and indirect way that ‘users’ or the ‘context of use’ influence research. In order to capture this, they constructed a “multi-dimensional typology” for “[u]nderstanding the characteristics of, and processes related to ... research” and in particular for understanding the “role of the user” in influencing the “research” (pp. 885, 886). The typology synthesises the authors’ extensive literature review and experience as researchers and decision makers of science policy (primarily in North America). The typology distils the multi-dimensionality of research into fifteen ‘attributes’ and ‘activities’ associated with a given research project or body of research. From my perspective, capturing this complex multi-dimensionality is important, as it highlights that there are many possible ‘moments’ of research in which academic boundaries can be crossed and confronted. I therefore slightly adapt the typology by conceptualising it through the ‘boundary’ lens adopted in this thesis, such that the typology becomes “a heuristic” (McNie et al., 2016, p. 893) tool for capturing insights into the ‘boundedness’ of different aspects (‘activities’ and ‘attributes’) of the sampled research. The (adapted) typology and its relevance to my interest in the ‘boundedness’ of research is presented below. The precise way in which I apply the typology for analytical purposes will be specified in the final section of this chapter (under the ‘Analysis’ sub-heading).

### The typology: fifteen attributes and activities of research and their boundary implications

Table 2 summarises McNie et al.’s (2016) fifteen attributes/activities which, they argue, combine to generate a full characterisation of a body of research. Given the interest that I and the typology’s authors’ share in the complex relations and ‘transactions’ between the context of academic knowledge production and that of wider society, Table 2 provides two summary descriptors of each attribute/activity: the table’s middle column (‘bounded’ research) provides a description of the attribute/activity in the context of a body of research which is strongly focused on working within and contributing to knowledge confined within the boundaries of academia, therefore taking negligible, if any, influence from actors, interests or objectives from beyond those boundaries; by contrast, the right-hand column (‘unbounded’ research) provides a description of the attribute/activity in the context of a body of research which engages with and pays strong attention to this external context. Of course, in reality, much research would fall between the extremes. The descriptions in Table 2 are therefore further elaborated upon below.

#### Goals

Academic research ranges from being highly theoretical, abstract, and curiosity-driven, with no preference for what the findings may be other than that they be accurate (‘bounded’ research), to being very applied, in some cases even being oriented towards achieving a specific outcome for some aspect of the social world (‘unbounded’ research), such as improved health, increased revenue, improving the effectiveness of a policy, etc (McNie et al., 2016, p. 888). Today, a new norm or middle-ground for academic research is what has been characterised as ‘use-inspired basic’ research (Hughes et al., 2016; Stokes, 1997), that is, research which is oriented towards producing knowledge of general relevance to the issues facing society, but does this by producing basic knowledge rather than by conducting research which has direct social outcomes. The goals of the research can be traced and ascertained through the outputs and structures associated with it.

|  |  |  |
| --- | --- | --- |
| **Attributes/activities** | **‘Bounded’ academic research** | **‘Unbounded’ academic research** |
| Goals | The goal is to *understand*; research is not constrained by specific outcomes. | Research is focused on achieving prespecified outcomes or impacts. |
| Relevance | Knowledge is broadly generalisable and has significant scientific implications. | Relevance is limited to specific, often localised, contexts of application. |
| Evaluation | Success is to be judged by scientific criteria (i.e. journal prestige, citations). | Success is to be judged in terms of the public value of research outcomes. |
| Outputs and outcomes | Traditional scientific outputs predominate, i.e. journal articles. | Outcomes directly engage wider publics, stakeholders and users. |
| Uncertainty | Reduce uncertainty by maximising precision and detail of understanding. | Adopt a ‘what works’ approach and accept that uncertainties will remain. |
| Knowledge exchange | Knowledge disseminated almost exclusively through scientific channels. | The sharing of knowledge with users is embedded in the research process. |
| Accessibility | Stakeholders outside traditional academic networks lack access. | Researchers aim to be accessible to multiple stakeholders and users. |
| Boundary management | Research proceeds within confines of traditional academic boundaries. | The need to cross boundaries raises boundary-management challenges. |
| Network | Networks are exclusively scientific. | Networks span non-academic and non-expert groups and stakeholders. |
| Flexibility | Research proceeds through traditional and unchanged organisational structures. | Research requires much flexibility to respond to external needs and events. |
| Disciplinary focus | Research problems and networks are anchored to scientific disciplines. | Research problems and networks are defined by contexts of application. |
| Social capital | Unnecessary to mobilise social capital; legitimacy derives from scientific rigour. | Mobilising social capital to build trust and legitimacy is key to research. |
| Expertise | Scientific expertise dominates; little/no involvement of other kinds of experts. | Non-academic expertise is key to the success of the BoR. |
| Learning | What is learned is ‘theoretical’, explicit and can be codified. | What is learned is practical, tacit or interpersonal. |
| Human capital | Specialised scientific skills and qualifications predominate. | ‘Soft’ skills and non-scientific skills and training are also important. |

Table 2. ‘Low’ and ‘high’ value descriptors adapted from McNie et al.’s (2016) typology

#### Relevance

‘Bounded’ research tends to focus only on expanding the generalisability of an academic discipline’s knowledge claims. Such research normally has “the aim of informing theories” rather than “solving a specific problem” and therefore tends towards abstract knowledge of potentially “broad” relevance (McNie et al., p. 887). By contrast, ‘unbounded’ research produces knowledge of more localised and direct relevance to a specific user or issue. Much academic research can be characterised as having a dual ‘relevance’, in that it makes modest theoretical advances with potentially broader scientific relevance, whilst also having likely relevance to specific user groups.

#### Evaluation

Evaluation refers to the criteria on which the research is expected to be judged. ‘Bounded’ academic research is likely to be produced with the expectation that it be evaluated according solely to ‘internal’ criteria, that is, by peer-reviewed assessments of scientific rigour and originality (McNie et al., 2016). However, increasingly, research is conducted with the expectation of achieving non-academic impact. In such ‘unbounded’ cases, the research might be considered a success to the extent that it generates revenue, saves lives or informs policies, regulations or practice. Again, a middle-ground is relatively common in academic research, particularly in science related to ‘open systems’ such as environmental research, such that success on evaluation according to scientific criteria (i.e. the resolution of a contested, complex scientific question) is an important step towards success according to external criteria (i.e. influencing environmental policy).

#### Outputs & outcomes

A key issue here is the intended audience of outputs and outcomes. ‘Bounded’ research would also likely aim at a similarly ‘bounded’ audience, i.e., one’s immediate scholarly community, with the intended outcome of the research being to contribute to the shared knowledge base of this specialist community. ‘Unbounded’ research might yield a greater diversity of outputs, for example taking the form of “trainings, public outreach activities, ... press releases, ...and expanded social networks” (McNie et al., 2016, p. 890). However, these ‘bounded’ and ‘unbounded’ outputs and outcomes can be blurred when external users have a high level of relevant expertise themselves. In such cases, the research might produce relatively ‘bounded’ outputs aimed at a relatively limited audience, but if this ‘limited audience’ included expert clinical practitioners, then the ultimate outcomes of this knowledge exchange would be significant and go well beyond the boundaries of academia.

#### Uncertainty

Uncertainty is an “inherent” (McNie et al., 2016, p. 885) feature of empirical research, and the way that researchers deal with ‘uncertainty’ can be thought of in terms of a trade-off. ‘Bounded’ research would typically aim to “reduce epistemic uncertainty” as much as possible by prioritising “accuracy and precision” (ibid., p. 888). But such results can often be complex and hard to interpret, particularly to those not with specialist knowledge of the topic. As such, ‘unbounded’ research, with a greater interest in informing some context of application or practice, would likely take a more pragmatic approach to uncertainty. That is, the researchers aim to produce knowledge that is sufficient for a given purpose, acknowledging that it will not lead to full understanding of the phenomenon. This could be summarised as a ‘what works’ approach.

#### Knowledge exchange

Knowledge exchange is an increasingly key concept amongst science policymakers and analysts for “understanding how to reconcile the supply of scientific information with users’ demands and increase the impact of ... research” (McNie et al., 2016, p. 888). ‘Bounded’ research would typically exhibit a “one-way communication from science to society”, for example “through peer-review publications” (ibid., p. 888). In such cases, researchers “communicate in ways that are consistent with, and understood by, their shared epistemic communities and not with the general public” (ibid., p. 888). By contrast, ‘unbounded’ research welcomes more iterative communications, and is “conducted in a language understood by researchers and users alike” (ibid., p. 888). As with the earlier case of ‘outputs & outcomes’, however, there is often a quite natural middle-ground for academics to tread, as key user groups often have some level of shared expertise with academics, making the knowledge exchange process relatively simpler and lower in ‘transaction cost’.

#### Accessibility

‘Bounded’ research typically prefers maintaining strong boundaries in terms of who is and is not able to access the academic institution. The ‘ivory tower’ image characterises the extreme end of this spectrum, in which academic research is “situated in departments, centres, schools, colleges or institutes, each of which has its own barriers to access both for users and other researchers” (ibid., p. 889). ‘Unbounded’ research prefers organisational structures adapted and designed in order “to facilitate easy access” (ibid., p. 889), both to and for potential users. Typically, *boundary structures* do attempt to facilitate eased access, but in a discriminatory way, making the university (or a particular section of it) accessible to some users and stakeholders, but not necessarily to the wider public.

#### Boundary management

McNie et al. (2016) introduce ‘boundary management’ as a research-related activity as follows:

“Whenever the two distinct worlds of science and society move closer to each other, the risk of science becoming politicized, or policy and decisions becoming ‘scientized’, becomes more acute... The boundary between science and society needs to be managed, by doing boundary work, in order to accomplish two mutual goals: ensuring that research responds to the needs of users while assuring the credibility of science.” (p. 890)

The key difference between ‘bounded’ and ‘unbounded’ research, vis-à-vis boundary management, is the extent to which “efforts [must] be made to actively manage the boundary” (ibid., p. 890). ‘Bounded’ research requires negligible interaction with non-academic actors, or involves interaction with actors who, for whatever reason, throws up no boundary-management issues for the academic – i.e. their identities, legitimacy and expertise are not challenged, nor is there any conflict of interest or clashes with academic values. Conversely, ‘unbounded’ research is likely to involve complex interactions with actors beyond academic boundaries, particularly where (i) they enter into arenas where their credibility or legitimacy is challenged or not accepted, for example, where their scientific advice might be questioned by stakeholders who may lose out if their advice is followed, or (ii) where the research has goals which potentially clash with those of academia, for example where commercialisation and revenue-generation force the academic to choose between secrecy or openness.

#### Network participation

Networks of researchers engaged in ‘bounded’ research are typically “homogenous and usually constrained within the researchers’ epistemic communities” (ibid., p. 889). By contrast, those associated with ‘unbounded’ research are more “heterogeneous” and “may include a wider variety of institutions including research, policy, business, community, and advocacy groups” (ibid., p. 889). Although similar to the descriptions for the earlier activity of ‘knowledge exchange’, ‘network participation’ is conceptually distinct, because networks may have functions other than exchanging knowledge, for example they may be part of an approach for finding challenging research problems faced by industry, or finding potential sponsors for research, or creating demand external for knowledge (Hughes et al., 2016).

#### Flexibility

Flexibility refers to the willingness and ability of organisations to make themselves amenable and accessible to other kinds of organisations (McNie et al., 2016). Organisational flexibility is often “restrained” (ibid., p. 890) in the case of ‘bounded’ research’, with non-academic organisations likely to face notable barriers to communication and collaboration with the university. By contrast, the openness and responsiveness associated with ‘unbounded’ research “requires higher degrees of organizational flexibility” (ibid., p. 890).

#### Disciplinary focus

‘Bounded’ research addresses problems and uses methods and techniques derived almost exclusively from its own core discipline. This might be considered a ‘traditional’ or ‘Mode 1’ form of academic research (Gibbons et al., 1994). But not all science has such narrow agendas, nor the luxury to be so ‘insulated’ (Bernstein, 2000). The concept of Mode 2 knowledge production (Gibbons et al., 1994; Nowotny et al., 2003) emphasises the shift in much academic STEMM research such that many research objectives derive primarily from real life problems, rather than from within disciplines. Summarising the Mode 2 thesis, McNie et al. (2016) note that an increasing amount of “research is transdisciplinary and is organized around problems that are defined by the context of use” (p. 888). In this context, disciplines are not necessarily irrelevant, but they are no longer the source of integrating experts; rather, the integrating factor is the collective ability of individuals, who may or may not be equipped with specialist disciplinary training, to contribute to particular outcomes. These are features of ‘unbounded’ research.

#### Social capital

Social capital refers to the way that one’s social position and personal networks can be mobilised to enable one to achieve desired goals (Al-Tabbaa & Ankrah, 2016; Inkpen & Tsang, 2005; Lambooy, 2010; Li, Liao, & Yen, 2013; Salaran, 2010; Van Wijk, Jansen, & Lyles, 2009). In many cases, social capital may not seem of great relevance to the process of research. In ‘bounded’ research contexts, what is important is the scientist’s academic credentials – social capital may seem superfluous when the application of “rigorous methods and norms” (McNie et al., 2016, p. 889) constitute sufficient symbolic, scientific capital to be considered a trustworthy and legitimate producer and transmitter of knowledge. “Leveraging social capital” can, however, be valuable, and “is particularly important in building capacity to apply knowledge in actual decisions and policies” (McNie et al., 2016, p. 889). Social capital may also be deployed in attempts to win funding and build networks with important collaborators and potential users. This is particularly the case where the researchers have not previously had the opportunity to build the “trust, and relationships ... necessary to create and share knowledge” (McNie et al., 2016, p. 889). Social capital is therefore likely to be of importance in ‘unbounded’ research contexts.

#### Expertise

STEMM research is an activity dominated by individuals with significant expertise normally grounded in years of disciplinary specialisation and socialisation, normally culminating in a PhD qualification. ‘Bounded’ research is dominated by such researchers. However, in more ‘unbounded’ research, other forms of expertise are important to achieve research goals. Non-scientific or “experiential” expertise that has been acquired in close “proximity to the problem”, such as “economic, policy, bureaucratic, community, lay and indigenous expertise” may be relevant and called upon (McNie et al., 2016, p. 887). In some cases, this may involve individuals who combine scientific andother forms of expertise, but in other cases it may mean collaborating with individuals without the normal academic qualifications, and whose expertise is solely derived from non-academic contexts.

#### Learning

The ‘learning’ attribute refers to what is or what can *be learned* as a result of the research. McNie et al.’s (2016) way of putting this is in terms of how the research results “*change the knowledge system*” (p. 888, original emphasis). Results of ‘bounded’ research typically take highly theoretical and/or highly codified forms, for example, a paper couched in highly technical, specialist terminology. The ‘learning’ that can be obtained from such outputs, or in other words, what can be learned from them, is “explicit knowledge” (ibid., p. 888) that can normally only be fully understood by others with similar prior knowledge as the researcher. The knowledge and the outputs therefore do not take into account more complex “social” or “practical” contexts where that research might be put to use (ibid., p. 888). By contrast, ‘unbounded’ research often generates more *user-focused outputs* which lend themselves to more socially contextualised forms of ‘learning’ where individuals who need to be able to learn from the research do not share specialist prior knowledge. Here, the relevant things to be learned by those who need to learn them may not easily be expressed in scientific, technical or theoretical language. Rather, more “tacit” and immediately practical learning may be needed. ‘Social’ or ‘practical’ knowledge is therefore “difficult to codify, takes time to explain and learn, and is embedded in relationships” (ibid., p. 888), and is likely to require greater effort on the part of the researcher/transmitter, for example through knowledge exchange and outreach.

#### Human capital

The last attribute is ‘human capital’. Human capital is clearly closely related to expertise. However, they differ in that expertise refers to specific contexts of one’s experience, the relevance of that experience to a given research/practical problem, and the way that expertise is mobilised at various points of the research process. Human capital refers to “the formal training and education required” (McNie et al., 2016, p. 890) in a given research context. In plotting this attribute against the typology, McNie et al. (2016) point to the role of “hard” and “soft” skills (p. 890). ‘Bounded’ research typically rests only on the “hard skills” associated with one’s formal training, that is, one’s ‘human capital’ (ibid., p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890) (McNie et al., 2016, p. 890). By contrast, in much ‘unbounded research’, a range of “soft skills”, such as “[e]ffective communication, translation and mediation skills ... and experience in managing ... complex research-policy interfaces” (ibid., p. 890), will also be important to achieving a goal. The point here is not to play ‘hard’ and ‘soft’ skills against each other, but rather that, in ‘bounded’ research, ‘hard’ skills are likely to be all-important, while in ‘unbounded’ research, they are likely to be insufficient, with ‘soft’ skills being as or moreimportant.

## Analytical framework

My analytical framework is derived from a combination of the three main sections of this chapter (*Power and control through the ‘boundary’ lens*; *Forms of boundary transaction*; and *Boundary transactions in context*). This can be condensed into a key theoretical idea: that boundary transactions take place in complex research contexts, and that they are key – albeit complex and not necessarily deterministic – causal mechanisms vis-à-vis the reproduction (or potential weakening or transformation) of academic boundaries.

I slightly adapt McNie et al.’s (2016) typology for my purposes by incorporating the notion of ‘boundedness’, derived from a Bernsteinian sociological lens and further developed through my broader review of literature on ‘boundary transactions’ which drew from the sociologies of higher education, science and organisation. Following the authors’ recommendations, I operationalise the typology by valuing the attributes/activities associated with given body of research on a spectrum of 1-5, where 1 denotes that a given activity/attribute was ‘strongly’ *bounded* or ‘insulated’, involving no or negligible interaction with or consideration of actors or issues beyond academic boundaries, while 5 denotes that the activity/attribute was *unbounded*, involving significant boundary-crossing transactions (see Table 2 above, p. 61). As I read through the documentary and interview data associated with the n=19 sampled bodies of research (BoRs), I seek evidence of and pay particular attention to ‘boundary transactions’. I make judgements about a BoR’s ‘boundedness’ on each activity/attribute and plot it on the typology’s spectrum accordingly (Appendix D shows the full plotted typologies for all BoRs). This allows me to *organise and quantify* my interpretation of the sampled research.

These quantifications then lend themselves to ‘interpretive quantitative’ analysis (Babones, 2016; Westerman & Yanchar, 2011). Quantified typology values belonging to individual BoRs will be aggregated in two ways to advance my analysis. First, I aggregate by attribute/activity. Within my analytical framework, ‘high’ values on the typology will be taken to indicate that the given activity/attribute has a boundary-crossing role associated with *unbounding* academia from society; by contrast, ‘low’ values on the typology will be taken to indicate that the activity/attribute is associated with reinforcing/reproducing academic boundaries. This contributes to my research questions by yielding indicators of the overall tendency of the sampled research towards the reproduction or potential weakening of boundaries, and of which aspects (activities and attributes) of research are primarily responsible. Second, I aggregate according to the three contextual dimensions; I analyse variations by research from different status departments (‘elite’, ‘more prestigious’ and ‘less prestigious’), different branches of science (Life, Natural, Formal), and different disciplinary orientations (Basic, Applied, Basic/Applied).

Within the critical realist ontological and epistemological framework adopted (see Methodology, Chapter 3), the above two sets of aggregated data are ‘surface’ level (Danermark et al., 2002, p. 59) phenomena. To obtain a deeper level of understanding of the underpinning causal structures and mechanisms determining the overall reproduction (or weakening) of boundaries, and whether indicators of reproduction (or weakening) vary by institutional and epistemic contexts, further analysis is needed. Specifically, from the Bernsteinian theoretical perspective adopted, what is needed is an analysis which yields insight into underlying interplays of power and control over academic boundaries and boundary-crossing activities. For this I conduct in-depth analyses of the specific boundary transactions associated with the sampled research, as well as in-depth interviews with some of the individuals responsible for the research. Further details of this analysis will be presented in the Methodology (Chapter 3), but I note here that they permit me to investigate how broader plays of power and control play out in specific contexts which contribute to either the reproduction or potential weakening of academic boundaries.

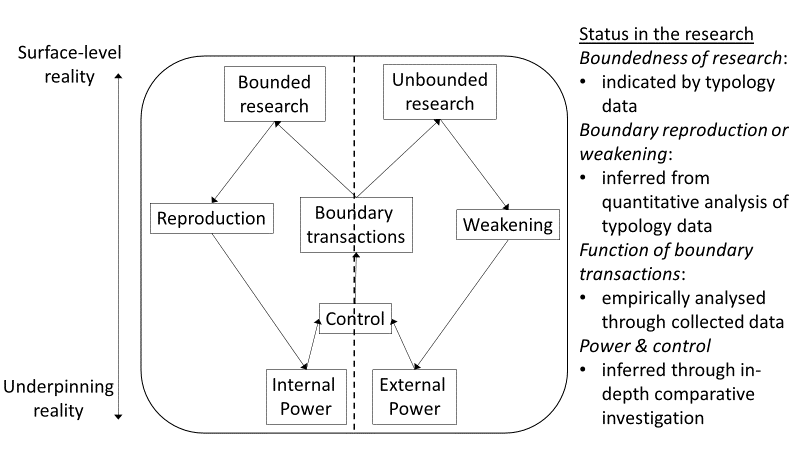
Figure 1 diagrammatically represents the key conceptual relations of the analytical framework, albeit not attempting to capture all its nuances. It highlights that internal and external sources of power operate to control the boundary transactions, and that these boundary transactions act mechanistically upon the research, such that: boundary transactions influenced primarily by internal sources of power operate to make the research more ‘bounded’, tending towards the reproduction of boundaries; by contrast, boundary transactions influenced primarily by external sources of power operate to make the research more ‘unbounded’, tending towards the weakening of boundaries. Power forces therefore tend to exert control over boundary transactions such that they reinforce their own sources of power. Conflicting underpinning structural realities, such as differing sources of power, will always be acting upon academia and academic research, so that it is an empirical question as to where the balance of power and control lies and what the implications are for the reproduction of boundaries. 

Figure 1. Conceptual framework of the functioning of research-related boundary transactions

In the Methodology (Chapter 3), I discuss the analytical procedures in greater detail and emphasise the alignment of each analytical procedure with the critical realist epistemological framework adopted. From the critical realist perspective, the final analytical step described above allows a level of inference which goes deeper than a surface-level explanation of observed events. From the critical realist perspective: the *underpinning sources* of power and control over boundary transactions leading to the observed variations in the typology data in different institutional contexts are conceptualised as *deep structural realities* whose existence *shapes and transcends* the specific phenomena studied, but *which interacts with more surface-level structures*, such as disciplinary and institutional context, in order to contribute causally to produce the observed effects. Thus, the in-depth comparative analysis of variations between contexts allows me to reveal some of the underpinning structural realities which continually act upon academia, albeit that their precise manifestation is mediated by other, more surface-level structural realities.

## Chapter summary

This chapter has reviewed a substantial and purposeful review of a range of theoretical and empirical literature. This started with an elaboration of the ‘boundary’ lens adopted, grounded primarily within a Bernsteinian sociology of ‘power’ and ‘control’ over academic knowledge, research and related activities. However, it also drew more widely from sociological theory, such as the sociology of science and organisation in order to add greater analytical clarity, particularly my use of the concept of ‘transactions’, which I linked to Bernstein’s notion of ‘control’. This comprised the first main section of this chapter.

Next, a still broader set of literature was drawn upon to identify different forms of ‘boundary transaction’, which I broke down into five main forms: outreach, collaboration, use-oriented outputs (‘boundary objects’), boundary structures, and boundary-spanners. This section of the literature gives some indication of how boundary transactions play out in actual contexts of academia’s relations with wider society and will help to orient and contextualise my empirical analysis by pointing towards the kinds of transaction I am likely to find in my own sample of STEMM research.

In the third main section of this chapter, I discussed McNie et al.’s (2016) typology and explained how it will be relevant to my analysis, providing me with a way to organise and quantify my interpretation of the sampled STEMM research, while simultaneously allowing me to capture the multi-dimensionality and complexity of research and research-related activities.

All of these strands of literature were brought together in the fourth and final main section, where they each contributed key elements to my analytical framework. In the following chapter, I present the methodology, which will explain how my methods of data and analysis will operationalise and implement this analytical framework, and how the analysis which this enables will be able to address my research questions.

# Chapter 3. Methodology

## Introduction

As a reminder, the main guiding research question for my study is: *What is the balance of ‘power’ and ‘control’ over the organisation, activities and societal relations associated with ‘high-impact’ academic STEMM research in the REF2014 context?*

Sub-questions:

1. *What role do different institutional and epistemic contexts play in shaping the balance of ‘power’ and ‘control’ over academic STEMM research?*
2. *What are the main forms and functions of ‘boundary transactions’ associated with the sampled academic STEMM research?*
3. *What are the implications of the balance of ‘power’ and ‘control’ for academic boundaries in the context of the ‘impact agenda’?*

This chapter explains and justifies my approach to answering the questions. In brief, a key tool used to address the overarching research question is a slightly adapted version of McNie et al.’s (2016) typology which allowed me to “holistic[ally] ... investigate, understand, [and] assess” (McNie et al., 2016, p. 893) the complex ways in which, and overall extent to which, the sampled bodies of research (BoRs) tended towards either strengthening or weakening (reproducing or reshaping, etc.) academic boundaries. The typology, introduced in Chapter 2 and also further explained later in this chapter, was designed to capture the full “multi-dimensional” (p. 885) complexity of research, with particular focus on the ways that the ‘user’, or at least researchers’ consideration of perceived users, can influence the research process. My adapted version, drawing on Bernstein’s interrelated concepts of ‘boundaries’, ‘power’ and ‘control’, allow me to conceptualise the results of the typology data as indicators of ‘power’ and ‘control’ over academic research, which I capture in the term *‘boundedness’* of research.

Plotting a given BoR against the typology’s fifteen attributes/activities yields data which lends itself to ‘interpretative quantitative’ (Babones, 2016; Westerman & Yanchar, 2011) analysis (see Figure 2 for an example of a plotted typology). Typology data from all n=19 BoRs can then be aggregated in various ways to yield insight into the overall extent to which the sampled research tends towards the maintenance and reproduction of boundaries or rather towards their weakening. At a greater level of granularity, they also highlight which activities/attributes of research tend to be mainly associated with the reproduction of boundaries and which with their weakening. This data can also be aggregated according to the institutional and epistemic contexts of the BoR, thereby directly addressing Sub-question (a).

I addressed Sub-question (b) by analysing the documentary and interview data to identify different forms of boundary transaction. A literature review (see Chapter 2) had already pointed to five main forms of boundary transaction (outreach, collaboration, boundary-spanning outputs, boundary-spanning individuals, and boundary-spanning structures). This helped me focus my search for important boundary transactions within the contexts of their specific BoRs. The combination of (i) a highly contextualised analysis of specific boundary transactions in their contexts, based on both documentary and interview data, and (ii) a more abstracted analysis of the ways in which and frequency with which the different forms of boundary transactions tended to operate in different contexts allowed me to fully address Sub-question (b).

|  |  |
| --- | --- |
| **Attributes/activities** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Goals | x |
| Relevance | x |
| Evaluation | x |
| Outputs and outcomes | x |
| Uncertainty | x |
| Knowledge exchange | X |
| Accessibility | x |
| Boundary management | x |
| Network | x |
| Flexibility | x |
| Social capital | x |
| Disciplinary focus | x |
| Expertise | x |
| Learning | x |
| Human capital | x |

Figure 2. Example plotted typology

Sub-question (c), with its focus on the ‘implications’ for academic boundaries more generally, relies not so much on any one specific method used, or set of data generated. Rather, inspired by the ‘critical realist’ (Bhaskar, 1998a; Danermark, Ekstrom, Jakobsen, & Karlsson, 2002) philosophical and metatheoretical approach adopted in this study (see below discussion), my approach to addressing Sub-question (c) involved positing and exploring potential explanations for the observed findings related to the preceding research questions. This meant taking stock of the full range of data in order to explore *what underpinning mechanisms and structures* are associated with, and help to explain, (i) the observed balance of power and control in the sampled research, (ii) the observed variations in terms of the ‘boundedness’ of the different activities/attributes (from the typology) associated with the sampled research, and (iii) the observed variations in the power and control associated with different institutional and epistemic contexts. The point of this line of analysis is that it helps me to develop a theoretical understanding of how specific contexts of academic scientific research mediate deeper social mechanisms and structures associated with the interplay of academic, scientific and other knowledge-related institutions, providing me with a more informed basis for thinking about the implications for the future of academic boundaries.

Moving forward in this chapter, I will start with a discussion of the critical realist approach to social science which has informed my research. I will then describe the methods used, including methods of sampling and of collecting and organising both documentary and interview data. I then detail my analytical procedures and discuss issues of validity and generalisability. Lastly, I will comment on ethical implications of the study.

## A critical realist approach to social science

### A three-layered framework of reality: the ‘empirical’, the ‘actual’ and the ‘real’

Critical realism provides both a meta-theoretical framework for the production of knowledge in the natural and human sciences, and a philosophical social theory for the emergence of social structures. In ‘critical realism’, the ‘realism’ refers to the belief that experiences and observed phenomena, both natural and social, reflect a reality that persists independent of our knowledge or consciousness of them. The ‘critical’ qualifies this view by emphasising that experiential, observable reality only constitutes the surface level of reality, the ‘empirical’ level. As such, no matter how rigorous, systematic and consistent our experiences and observations may be, our knowledge always has the potential to be fallible or incomplete to the extent that it relies only on such experiences and observations. Bhaskar (1998a, 1998b), widely credited as the founder[[7]](#footnote-7) of critical realism, posits a three-layered framework of reality, from which critical realism derives both its ontology (how critical realism conceptualises the world to be) and its epistemology (how critical realism believes our knowledge of the world is structured). The three layers are the *empirical*, the *actual* and the *real*.

The *empirical* refers to phenomena and events which occur and to which we have some sensual or experiential access. However, not every event that *actually* occurs is, or can be, experienced or observed directly. The *actual*,therefore, is distinct from the *empirical*, in that the *actual* refers to all phenomena and events, not just those which we (have the capacity to) experience. This distinction achieves two things. Firstly, it makes explicit within the ontological framework the possibility that there exists a (social) world beyond humans’ experience of it, or our capacity to sense it. Second, it presents an epistemological imperative for how science, natural or social, ought to proceed. That is, (social) science is not advanced by merely listing, experimenting, and describing events and their conditions, but rather by positing and testing theories about the underlying generative *mechanisms* that produce these conditions and events. For example, natural science (biology) has theorised that the empirically observed evolution of species *must* imply the existence of the underpinning mechanism of natural selection. Similarly, social science (economics) has theorised that certain empirically observed successes and failures of private companies *must* imply the existence of underpinning market mechanisms[[8]](#footnote-8). In both these cases, the underpinning mechanisms, those of natural selection and of the market, are not visible directly, but only in their effects, so that our endeavours to generate knowledge of these mechanisms must ultimately proceed by making inferences about the unobservable based on observable phenomena and, where possible, attempting to test these inferences. In Bhaskar’s (1998a) words, “mechanisms, events and experiences thus constitute three overlapping domains of reality, vis. the domains of the real, the actual and the empirical” (p. 19), so that it is “the structures and mechanisms that generate phenomena” (p. 41) which constitute the “objects of [social scientific] knowledge” (p. 41).

### A critical realist research design

Epistemologically, then, generating new knowledge begins from the following question: if experienced and observed phenomena are real, what inferences can we make about the nature of (social) reality? In other words, for critical realism, knowledge claims ideally take the form of theories and revelations about *what must be the case* for given empirical phenomena to be ‘real’. The cognitive operations are ‘abductive’ and ‘retroductive’ reasoning, where ‘abduction’ refers to the process of theorising about possible structures and mechanisms which could have led to observed phenomena, and ‘retroduction’ to the process of scrutinising and testing the various causal elements that are assumed, posited, or implied by such a theory (Danermark et al., 2002, pp. 109-110). However, abductive and retroductive reasoning face an additional problem in social science that is not faced by natural science, namely, the structure-agency problem. Social science must attempt to account for the mutually and reciprocally determinative nature of the relationship between social structures and human agency. This is because human agency cannot be understood apart from the socially structured contexts in which it takes place, but at the same time, social structures cannot be understood apart from the human activities through which these structures are themselves (re)produced and transformed.

A novel move that the above framework allows Bhaskar to make is to present this dynamic between structure and agency not just in the negative sense, as a problem or a tension for social scientists to grapple with. Rather, this problem takes on a positive aspect, in that it is precisely this property of societies, social institutions, and social action, that makes societies, social institutions and social action *possible objects of knowledge* for social science. This is the case because if observable social institutions and activities constitute the surface, ‘empirical’level of reality, then, according to the critical realist framework, this necessarily implies that there must be some unseen underpinning interaction and interplay between, on the one hand, the human *agency* driving social activities, and on the other, the social *structure(s)* within which all social activity takes place. In other words, social forms, social institutions and social activities are the “emergent properties” (Bhaskar, 1998a, p. 41) and *observable* realities of the *unobservable* interaction between human agents and social structures. This is not intended to “explain away” (Danermark et al., 2002, p. 61) the structure-agency problem, since it remains the case that social scientists will be confronted with the structure-agency problem in any given research context, and that any social activity “may, in general, be described either in terms of the agent’s reason for engaging in it or in terms of its social function or role” (Bhaskar, 1998b, pp. 38-39). However, the above insight provides a philosophically-grounded rationale for proceeding with social scientific research and theorising in the face of the structure-agency problem on the basis that all social science has the potential, in principle, to contribute to knowledge of how the structure-agency interrelationship played out to generate the empirical phenomena being studied.

### Implications of critical realism for social science research

A practical research implication is that all data should be considered only partial in terms of what they reveal about reality. For example, even the most thorough, intelligent and reflexive accounts of individuals in, say, a research interview situation, are unlikely to fully reveal the complex social reality that underpins any given activity that an individual has conducted, or any phenomenon experienced. The critical realist social scientist is therefore required to be critical of his or her own data. In Bhaskar’s (1998b) example, “we do not suppose that the reason why garbage is collected is necessarily the garbage collector’s reason for collecting it” (p. 39). In my own case, I must bear in mind that the reasons that individual academic scientists have for conducting a particular project or related activity in a particular way, or with a particular collaborator, may not perfectly correspond to the reasons that the university, sponsors, other collaborators, and wider society have for allowing, valuing and supporting the conditions which allow this scientific activity to occur – indeed, some evidence from interviews with academic scientists suggests they are “generally articulate about needing resources, but not about the political alliances that shape funding” (Slaughter et al., 2004, p. 139).

Critical realism also has broader implications for how we should approach social scientific research, including the role of theory and methods. The generation of new knowledge by abductive and retroductive reasoning can in principle be attained with the support of any method of data collection and analysis. Critical realist research therefore permits of all forms of qualitative, quantitative or mixed methods, and of a whole range of data sources. Within given projects, inductive and deductive reasoning can both also have their place, although critical realism would conceive of these as auxiliary to processes of abduction and retroduction (Danermark et al., 2002; Sayer, 2010). Most important is that for critical realism, and for abductive and retroductive reasoning more generally, theory takes priority as the driver of new knowledge generation: theorising about “generative mechanisms” can be considered the “main undertaking in research” so that “theory should guide research and not be subordinate to specific methodological rules of how research should be conducted” (Danermark et al., 2002, pp. 2, 154).

Regarding the compatibility of my philosophical and my theoretical influences, Bernstein (2000) is himself equally clear that theory is the main driver of knowledge-generation – “the theory, however primitive, has always come before the research” (p. 93). Indeed, the compatibility of Bernstein with critical realism has been emphasised by recent Bernsteinian scholarship. Bernstein’s intellectual ‘offspring’ (his students and theirs) have explicitly drawn on Bhaskar’s critical realism to build upon Bernstein’s legacy in the sociology of education, primarily in order to make the case for a social basis for the objectivity of knowledge and for the centrality of knowledge in educational curricula, coalescing around what they term ‘social realism’ (Maton & Moore, 2010; Young, 2008). And the following accounts of Bernstein’s work clearly indicate the theory-driven abductive and retroductive reasoning at its heart:

“Theory, for Bernstein, has at least a two-pronged role. The first is to grasp the real... But the real itself is to be understood not in a static sense but in a dynamic one; every actually existing real nurtures within it a series of logical alternative possible futures. This second, pre-eminent role of theory is to grasp the real as the realization of only one of a series of logical possibilities.” (Muller, 2004, p. 4)

“Theory comes first and the first task of theory is the construction of ‘models’. ...The model’s principles act as *generative* principles that describe in *theory* a range of possible ‘somethings’ that *might* be empirically present... The key methodological issue is to refine the concepts generated by the theory ... in such a way that theoretical constructs can be matched against *actual* manifestations of ... real ‘things’ in the *real* world.” (Moore, 2013, p. 126, original emphases)

My research has indeed been driven primarily by theory, specifically the theoretical framing of universities through the boundary lens (Vakkuri, 2004). This allowed the problem of the role of universities in the context of the impact agenda to be framed in terms of the relative strength and shape of academic boundaries.

## Methods

### Sample and sampling strategy

Qualitative critical realist research emphasises *context* – it involves intensive study of the contexts of phenomena of interest in order to understand structures and mechanisms which help to explain how the phenomena of interest play out in the ways they do(Danermark et al., 2002; Kessler & Bach, 2014). My study seeks to understand research-related academic boundary transactions and their role in influencing the reproduction or potential weakening of academic boundaries. It therefore studies boundary transactions in their contexts.

I chose to sample cases of academic research that had been recognised for their non-academic ‘impact’. The reasoning underpinning this was that it seemed likely that research which had made a significant impact beyond academia would be rich in instances of boundary transactions, and it was essential to my study’s aims that I was able to identify and study boundary transactions in their contexts of research. I selected my sample among bodies of research (BoRs) which had contributed to an Impact Case Study that had received a 3-4\* rating in the Impact assessment in REF2014. Although this approach was successful in directing me to BoRs which included a rich and broad range of boundary transactions, it is important to acknowledge that this decision led my documentary analysis to study very successful BoRs, and led my interviews to disproportionately focus on the experiences of very senior, successful and, as it turned out, almost exclusively male academics (see demographic details discussed in the final pages of this chapter). The experiences and activities are therefore not likely to be representative of the wider population of (STEMM) academics. However, as I will show in Chapters 4-6, this did not prevent me from making other kinds of claims of generalisability, including “transferability” of concepts (Gomm, Hammersley, & Foster, 2000, p. 98) and what Sayer (2010, p. 239) refers to as ‘generality’, that is, showing similar mechanisms or processes playing out under a range of different conditions and contexts. Moreover, as others have noted, the approach can help to “make inferences about the kind of impact that was valued in the REF process, and the kind of research leading to such impact” (Laing et al., 2018, p. 175).

As indicated by my research questions, I wanted to capture various academic research contexts shown to be important in shaping academic life and experience in general, namely, *institutional* and *epistemic* context. I therefore adopt a “maximum variation” [[9]](#footnote-9) sampling strategy (Miles & Huberman, 1994, p. 28) to capture a range of institutional and epistemic contexts. There are two aspects of *institutional context*: university status and departmental ranking. Regarding institutional status, I refer to and adopt Boliver’s (2015) recent work. Her cluster analysis results in a four-tier structure of UK academic hierarchy: an elite Tier 1 includes only two institutions; Tier 2 comprises 39 institutions; Tier 3 is the largest, including 67 institutions; last, there is a small cluster of 19 institutions which make up Tier 4 (Boliver, 2015, pp. 619-620). My sample strategy targeted BoRs based in universities from all four clusters/tiers. Next, regarding departmental ranking, I identify departments whose ‘Overall’ REF rating was relatively ‘high’, ‘middle’ and ‘low’ in relation to others within the same UoA. I ascertained these rankings from the Times Higher Education's (2014) publication of institutions ranked by UoA performance. Based on this, the submissions in my sample which I characterise as ‘High’ rank between 1st and 6th in their respective UoAs, while those characterised as ‘Medium’ rank between 9th and 28th, and those as ‘Low’ from between 37th and 40th.

There are also two aspects to *epistemic context*: branch of science and research “orientation” (Hughes et al., 2016, p. 30). Branch of science includes the categories of Life sciences, Natural sciences and Formal sciences. Research orientation refers to whether a discipline is Basic, primarily oriented towards the advancement of understanding of phenomena, or Applied, oriented primarily towards finding and testing novel applications of knowledge[[10]](#footnote-10). My sample includes disciplines from all branches of knowledge and from Basic and Applied disciplines. Figure 3 presents a visualisation of how the ten sampled disciplinary groupings (UoAs) can be conceptualised in terms of their epistemic context.

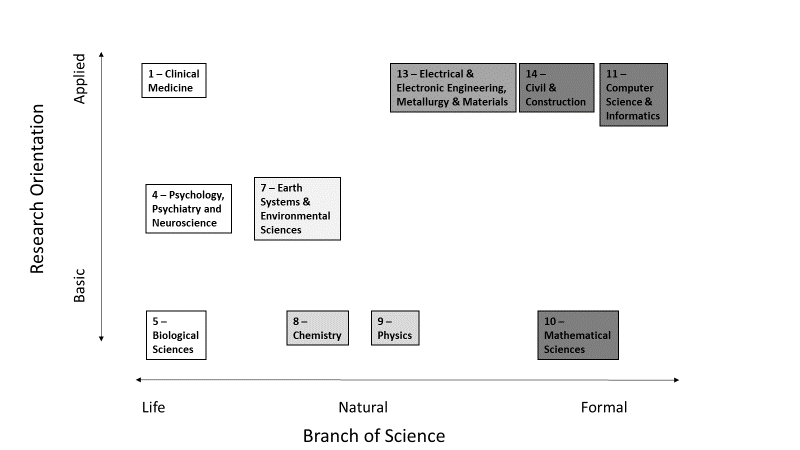


Figure 3. Visualisation of epistemic categories of sampled REF2014 UoAs

Table 3 details the epistemic and institutional characteristics of the ten sampled departments[[11]](#footnote-11). The bottom row shows that this sample succeeds in representing a broad variation of departments, as well as achieving parity in most of the parameters: the sample includes a minimum of one from each of Boliver’s (2015) four tiers; Applied and Basic disciplines are equally represented; each branch of science is equally represented; Medium-rated departments are slightly more represented than High-rated and Low-rated departments. The ten REF submissions presented in Table 3 produce 51 Impact Case Studies to REF2014. I selected half (26) of these for analysis. However, on inspecting these 26 Impact Case Studies, it became apparent that there were some cases where departments had submitted more than one Impact Case Study based on the same underpinning research. I collated those Impact Case Studies. This resulted in a final sample of n=19 (rather than 26) distinct underpinning bodies of research (BoRs) on which I conducted my main analytical procedures, discussed in the rest of this chapter. Appendix B provides further methodological details, including of the sampling strategy.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***REF2014* Unit of Assessment (UoA)** | **Institutional context** | | **Epistemic context** | |
| **Institutional status** | **Department REF rating** | **Research orientation** | **Branch of science** |
| 1 (Clinical Medicine) | Tier 2 | Medium | Applied | Life |
| 4 (Psychology, Psychiatry & Neuroscience) | Tier 4 | Low | Basic/Applied | Life |
| 5 (Biology) | Tier 2 | Medium | Basic | Life |
| 7 (Earth Systems and Environmental Science) | Tier 3 | Low | Basic/Applied | Life/Natural |
| 8 (Chemistry) | Tier 2 | Medium | Basic | Natural |
| 9 (Physics) | Tier 2 | High | Basic | Natural |
| 10 (Mathematical Sciences) | Tier 2 | Medium | Basic | Formal |
| 11 (Computer Sciences & Informatics) | Tier 3 | Low | Applied | Formal |
| 13 (Electrical & Electronic Engineering, Materials & Metallurgy) | Tier 1 | High | Applied | Natural/Formal |
| 14 (Civil & Construction Engineering) | Tier 2 | High | Applied | Formal |
| **Totals** | T1 (1)  T2 (6)  T3 (2)  T4 (1) | High (3)  Medium (4)  Low (3) | Basic (6)  Applied (6) | Life (4)  Natural (4)  Formal (4) |

Table 3. Characteristics of sampled departments

### Data collection

#### Documentary data

From the critical realist perspective adopted in this thesis, one of the most valuable features of qualitative research and its focus on particular cases is the opportunity for “closeness” to the “natural context” (Danermark et al., 2002, pp. 158, 175). Most recent qualitative sociological knowledge of academic work and knowledge production has achieved this closeness through participant-based studies, primarily interviews but also in some cases ethnographic data (see the Literature Review, Chapter 2). Research which does not adopt such methods also tends to foreground participant-based data in the form of quantitative surveys. My research complements and contributes to this body of knowledge through a study primarily driven by documentary sources which provide insights into academic research work and its context. Atkinson and Coffey (2004) have made the case for greater use of documentary sources in such contexts:

“Many published studies of, for example, occupational, professional, organizational and even educational or academic settings are implicitly represented as devoid of written documents and other forms of textual recording. ...[I]t is necessary to redress the balance if only for the sake of completeness and fidelity to the settings of social research.” (p. 56)

They go on to provide further explanation and justification directly pertinent to my own decision to focus on documentary sources. Such research settings as academic contexts, they write, are

“routinely, often extensively, involved in the production and consumption of written records and other kinds of document. ...Many ... of those documents are produced for external, even public, consumption. They may be among the methods whereby [academic] organizations, compete with others in the same marketplace or justify themselves... In the contemporary world, we should also include ... websites, promotional videos and similar artefacts. These are all among the techniques and resources that are employed to create versions of reality and self-presentations.” (Atkinson & Coffey, 2004, p. 57)

The above passage describes well the kinds of documents I gather for my analysis. Figure 4 summarises my 345 documentary sources. They include 46 documents related to the ten sampled departments’ REF2014 submissions (26 Impact Case Studies, 10 Impact Templates and 10 Environment Templates[[12]](#footnote-12)) as well as 301 documentary sources related to the actual BoRs which underpin the Impact submission. Central among these BoR sources are the 152 academic outputs which were referenced in the ‘Underpinning Research’ sections of the Impact Case Study. These were supplemented by a further 23 documents and 126 websites related to the research and its context, including research grant proposals and web profiles of specific centres and non-academic collaborating organisations.

|  |  |  |
| --- | --- | --- |
| **Source** | **Type** | **Quantity** |
| REF submissions | Environment Template | 10 |
| Impact Template | 10 |
| Impact Case Studies | 26 |
| BoRs | Academic outputs (referenced in Impact Case Studies) | 152 |
| Other documents | 23 |
| Web sites | 124 |
| **Total** | | **345** |

Figure 4. Documentary and web-based data sources

While using these data, I acknowledge Atkinson and Coffey’ (2004) caution that documents are representations of “a particular kind of documentary reality” (p. 61). Such documents as produced in the context of “audit exercises like the RAE [or REF] ... are intended to reflect the *coherence* of a department’s research strategic thinking and the *cogency* of its research plans” (Atkinson & Coffey, 2004, p. 70, emphasis added), rather than the more complex and ‘messier’ aspects of the reality of academic research. Although providing valuable factual information, they must not be received uncritically, nor as a sole source of data for the critical realist qualitative researcher interested in the specifics of the research *context*, since one of the features of such documents is precisely that they “*de-contextualize* events” (Atkinson & Coffey, 2004, p. 69, emphasis added).

Atkinson and Coffey’s (2004) cautions about using such documents are perhaps even more relevant in the context of REF2014 than in their context of the RAE. This is because REF2014 requires highly performative documents from departments, particularly the Impact Case Study narratives, which are carefully structured and presented to align with the REF’s impact criteria of ‘reach’ and ‘significance’. I therefore emphasise that I treated these documents (and indeed all documents, since the critical realist perspective is that no single source of data fully and unproblematically reflects reality) with due caution. My main uses of the REF documents were to obtain a broad overview of the underpinning research and to identify the key academic and non-academic actors and organisational structures associated with the research. Overall, Impact Case Studies constituted only 8% of the documents studied, so my analysis was informed by a far broader set of documents, each of which I treated as representing only partial reality.

#### Interview data

I aimed to interview one individual from each of the n=19 BoRs. I started by contacting key researchers associated with the sampled BoRs. In many cases the first person I contacted responded positively. I made a decision that where an invitee responded to turn down the invitation, that I would not pursue further potential respondents associated with that BoR. However, where I received no response, I then invited another potential respondent associated with that BoR. In total, I interviewed ten participants, and these ten participants were involved in 14 of the 19 sampled BoRs (and 19 of the 26 sampled Impact Case Studies from which the BoRs were derived, as discussed earlier), since some of the respondents were involved in more than one BoR. Among the ten participants, nine were my first choice for that BoR, as they appeared to be leading researchers in that BoR. The final participant was heavily involved in one BoR, and had some involvement in another, but was not the leading researcher on either. Among invitees who did not participate, most simply did not respond to my invitation (having sent them one physical letter and one follow-up e-mail). However, one invitee responded saying that they were interested in the study but unfortunately unable to participate due to significant time pressures, and one participant responded saying they were unwilling to participate (this was a person who was not my first choice respondent related to the BoR, as other potential participants had not responded, and this person’s response was that they did not feel best placed to talk about the research, as they had not led on it). Due to non-responses and non-participation, there were five BoRs analysed which were not represented in the interview participants. The ten interviews resulted in over eleven hours of recorded audio data and over 60,000 words of transcribed data.

Just as the relationship between research questions and research design is not solely logical, a critical realist interview similarly “avoids the temptation to simply convert *research method* questions into *research interview* questions” (Roberts, 2014, p. 5, original emphasis). The approach to interviews therefore needs to be specific and purposeful, rather than follow a generic formula or procedure. This section discusses my understanding of interview data and describes how I have gathered and used such data. Further relevant details about the interviews are also given in the Analysis and Ethics sections of this chapter.

Although there are limitations to the research interview, being able to directly hear from the ‘voice’ of academic researchers – “the principal human agents of scientific processes” (Elias, 1982, p. 5) – has been a highly valuable additional source of data for my study. Interviews are possibly the most common data-collection methods in qualitative research, allowing the social scientist to gather data about events and phenomena to which they otherwise have little or no direct access (Holstein & Gubrium, 1995; C. Smith & Elger, 2014). A critical realist researcher should aim to maximise the value of research interviews whilst also acknowledging their limitations. This means receiving interview accounts critically and combining them with other sources. As C. Smith and Elger (2014) write:

“Interviews, the dominant means of accessing information in social research, are not a neutral tool. ... Realist interviewing is more than simply *recording* informants... The interviewer needs to critically evaluate informants’ accounts against their [the researcher’s] theories, knowledge and understanding. Critical realist interviewing is also concerned to draw on resources and information external to the interview context, in order to scrutinize accounts.” (C. Smith & Elger, 2014, p. 109, original emphasis)

Having drawn my data mainly from documentary sources, the interviews served to “provide additional information that [may have been] missed” in my documentary searches, and “to check the accuracy” of my interpretations (Maxwell, 2013, p. 103). Maxwell (2013) notes that “[f]or interviewing to be useful for this purpose, you need to ask about *specific* events and actions, rather than posing questions that elicit only generalizations and opinions” (p. 103, original emphasis). My own interviews were indeed predominantly focused on specific details related to my interviewees’ direct participation in research which I had sampled for study. Interviews were semi-structured and somewhat tailored to each individual respondent, with individualisations grounded on my prior knowledge their research and broader academic work based on my documentary research. However, I started each interview by asking relatively open questions which would give the respondent their own opportunity to ‘shape’ the narrative of the BoR. I made a particular point to ask follow-up questions and clarification where their version of events surrounding the BoR suggested different or more complex interpretations to those which I had gleaned from the documentary sources, for example if the precise order of events or meetings with key collaborators seemed more complex in the respondents’ telling, or if ‘hidden’ collaborators or inspirations for the research were mentioned. My probing questions encouraged the respondent to reflect on processes of collaboration and communication with different audiences, including various funders, collaborators, stakeholders and users of knowledge – anything which I felt was an important part or instance of confronting academic boundaries.

This semi-structured line of questioning yielded illuminating conversations and rich data. As the dialogue unfolded, several of the respondents seemed to take the opportunity to reflect on their research more discursively and/or critically. For example, after one respondent expressed the opinion that professional practitioners should attempt to instil more ‘curiosity’ into their work – curiosity being a trait normally deeply associated with ‘blue skies’, basic academic research – I asked the respondent if she had attempted to conduct any such collaborative research with professional practitioners herself. She responded she “ha[d]n’t really ... perhaps I ought to do that” and thanked me at the end of the interview for giving her the opportunity to reflect on how her research trajectory in relation to her research values. Two respondents used my questions about their collaborations with non-academic organisations to frame their experience in terms of crossing “boundaries” – the central concept in my study, but a term which I had deliberately not used with the participants either in writing or verbally at those points of the interview (see Appendix B for the letter to participants and interview Information Sheet). Another respondent framed his answer in terms of “academic identity” and spoke quite *sociologically* about his conflicting ‘identities’ in relation to his university, discipline, and personal motivations, each of which seemed to take him in different directions. I believe that these examples indicate the success of my interview approach, which was to elicit respondents to give their own accounts of the research, with as little input from myself as possible, and then to gradually probe and encourage reflection on issues of more theoretical interest to me, grounded in my existing detailed knowledge of the participants’ research[[13]](#footnote-13).

## Analytical procedures

### Analysis of n=19 bodies of research (BoRs): the ‘surface-level’ of research boundedness

A key theoretical idea, which condenses and combines the various sub-sections of the literature review (Chapter 2), underpins my analytical framework: Boundary transactions are key causal mechanisms vis-à-vis the reproduction or potential weakening or transformation of academic boundaries, but they take place in complex research contexts, are not necessarily directly deterministic, and require in-depth study in order to untangle their operation and effects. Therefore, understanding boundary transactions requires not only analysis of the transactions themselves, but also an analysis at the level of the ‘bodies of research’ (BoRs) within which these transactions occurred, and which takes seriously the complexity of the research context. What is needed is (i) evidence of how ‘boundary transactions’ played out in context *and* (ii) evidence about whether the context of research was relatively ‘bounded’, and therefore boundaries were predominantly being reproduced (‘bounded’), *or* ‘unbounded’, and therefore boundaries were predominantly being weakened, and in what ways. The diagrammatised conceptual framework, first presented in Chapter 2 (Figure 1) and reproduced below (Figure 5), helps to clarify this point. Boundary transactions take place in the contexts of research which are more or less ‘bounded’.

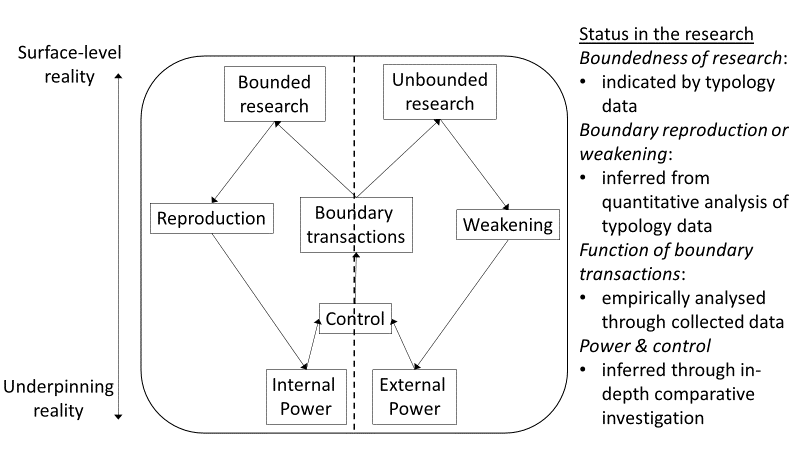


Figure 5. Conceptual framework of the functioning of research-related boundary transactions

#### Plotting the BoRs against the typology

Central to this task is plotting all n=19 BoRs against the typology adapted from McNie et al. (2016)[[14]](#footnote-14). Figure 6 shows an example of a fully plotted typology. The typology aims to quantify my interpretations of the *boundedness* (as defined in the final section of Chapter 2 under the ‘Analytical Framework’ sub-heading) of a given BoR, taking into account the multidimensional complexity of the research process so that I can capture the possibility that research might exhibit more ‘boundedness’ in some ways than in others. As Figure 6 shows, plotting a BoR against the typology involves making a judgement about where the BoR lies on a spectrum of 1-5 for each of the fifteen attributes/activities, where 1 refers to the research being very ‘bounded’ on the given attribute/activity, and 5 being very ‘unbounded’ – the concept of ‘boundedness’ and my operationalisation of it is discussed in the *Analytical framework* section of Chapter 3 (e.g. Table 2).

|  |  |
| --- | --- |
| **Attributes/activities** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Goals | x |
| Relevance | x |
| Evaluation | x |
| Outputs and outcomes | x |
| Uncertainty | x |
| Knowledge exchange | x |
| Accessibility | x |
| Boundary management | x |
| Network | x |
| Flexibility | x |
| Social capital | x |
| Disciplinary focus | x |
| Expertise | x |
| Learning | x |
| Human capital | x |

Figure 6. Example plotted typology

As McNie et al. (2016) emphasise, plotting the typology is inevitably “a subjective activity” (p. 891). However, I made myself well-informed to make these judgements through my intensive reading of the documentary data, as well as gaining insights directly from relevant researchers via interview (for fourteen of the nineteen BoRs). Throughout the plotting process, I frequently went back and forth comparing values I had plotted for different BoRs and different phases to check that all of the values plotted reflected my best judgement, and that my standards were not changing over time. After I completed plotting all values, I went back to the beginning and checked each value once more in light of having now got the perspective of the whole set, and there were some values that I altered at this stage. All of the n=19 BoRs’ plotted typologies are presented in Appendix D.

Two further points should be made about the typology analysis of the n=19 BoRs and typologies before describing the way in which I used the aggregated typology data for ‘interpretative quantitative’ analysis (Babones, 2016; Westerman & Yanchar, 2011). First, in Appendix D, the reader will notice that the nineteen typologies (one per BoR) have not one value per attribute/activity, but three. This is because I chose to plot all BoRs three times, at three distinct temporal ‘landmarks’ or what I call ‘phases’. This made sense in my case because some of the BoRs took place over long timescales, therefore differing from the shorter-term projects that the typology’s original authors studied. A single figure to describe the attributes/activities for a whole BoR, some of which describe research over a two-decade period, seemed to me overly reductive since research might be more or less ‘bounded’ over time. To strike a balance between capturing more complexity whilst keeping analysis manageable, I conceptualised all BoRs as consisting of three distinct ‘phases’. The phases did not correspond to any *a priori* understanding of the ‘phases’ that academic STEMM research goes through, but simply an acknowledgement that there are often important milestones or new directions in a body of research that marks a shift, possibly including a shift in the *boundedness* of the research activities/attributes. This allowed a more nuanced assessment of the BoRs’ boundedness. For analytical steps which relied on aggregating typology values (described below), I used the average values of all three ‘phases’.

Second, alongside the plotted typologies, Appendix D also presents narrative descriptions of each BoR. Presentation of these narratives are important for a few reasons. They serve as a condensed version of my understanding and interpretation of the BoRs based on the documentary and interview data. They can be referred back to for my own purposes but also by others to view and potentially scrutinise my interpretations. This is important because narrative accounts of events are never neutral or unambiguous ‘truths’ but rather they are specific and potentially fallible claims to knowledge[[15]](#footnote-15) – in my case, knowledge about the important boundary processes associated with a given BoR.

#### Analysing the BoRs using the typology data

The data derived from plotting the nineteen BoRs against the typology lends itself to ‘interpretative quantitative’ analysis (Babones, 2016; Westerman & Yanchar, 2011). As already discussed, I am interested in how particular features of the research context may shape boundary transactions and their role in reproducing or potentially weakening academic boundaries. The ‘research contexts’ I am interested in relate to *institutional* and *epistemic* context. Analysis of the typology data therefore involves aggregating the data to different institutional and epistemic contexts to allow comparison. For example, I can compare the average typology values of: Life, Basic and Natural sciences; ‘elite’ and ‘non-elite’ institutional contexts; and Basic and Applied disciplines[[16]](#footnote-16).

To better understand the relationship between research context and the boundedness of research, I use the same ‘aggregation’ method to explore whether there are any patterns emerging related to the typology’s fifteen attributes/activities. That is, I explore if and why some research activities/attributes are systematically more associated with reproducing boundaries and some more associated with weakening boundaries.

#### Interpreting the analysis of typology data

The aggregated values are interpreted as indicators of the ‘boundedness’ of research sampled from different contextual categories, say from Applied disciplines, Life sciences, or ‘elite’ institutional contexts. ‘Boundedness’ is, in turn, interpreted as the extent to which research in a given category tends towards the reproduction or weakening of academic boundaries. In respect of the critical realist framework adopted, these have the epistemic status of ‘surface-level’ empirical observations, and as such they require further analysis to understand their underpinning causal mechanisms and structures.

For this, I turn to a detailed analysis of boundary transactions. This is in line with the theoretical ‘boundary lens’ adopted, which sees boundary transactions as causally important in the reproduction or otherwise of boundaries (see Chapter 2). Following the aggregation of typology values, the main things to be explained are:

* + The sample’s *overall* tendency towards the reproduction or weakening or academic boundaries (as it turns out, the data point more towards boundary reproduction than weakening);
  + Variationsby different research contexts (i.e. institutional and epistemic context).

This is addressed in the next phase of analysis, discussed below.

### Analysis of boundary transactions in the BoRs: operational mechanisms

In Chapter 2, boundary transactions were conceptualised as key mechanisms vis-à-vis the reproduction or otherwise of academic boundaries. An important first step is therefore to identify boundary transactions in my sampled BoRs. This step can be thought of as ‘qualitative data-mining’ – a form of qualitative content analysis (Holsti, 1969; Schreier, 2014; Titscher, Wodak, & Vetter, 2000), in which documents are analysed “as containers for content” (Prior, 2008, p. 479) through “the mining of the narrative text contained in documents” (Henry, Carnochan, & Austin, 2014, p. 8). I read through the data associated with the n=19 BoRs, starting with the documentary materials and, later, the interview transcripts, to identify any boundary transactions associated with my sampled research. The literature review (Chapter 2) provided the initial frame of five main forms of boundary transaction and this helped to guide my reading and focus. I also inductively coded sub-forms of some of these five main forms.

Table 4 summarises the main forms and, where applicable, sub-forms of boundary transaction identified in the sampled research. It shows that I coded any form of ‘Outreach’ under this broad heading[[17]](#footnote-17). For ‘Collaboration’, I chose onlyto code where there were actual instances of *co-authoring* outputs, such as patents or papers. I made this decision because the notion of ‘collaboration’ could cover such a broad range of relationships. Although this means that collaborations are likely to be undercounted under the ‘Collaboration’ heading, this is partly made up for in the other headings. For example, ‘outreach’ and ‘boundary-spanners’ both imply a relation with some external, non-academic organisation, and this relationship could be conceived of (at least in some, if not all cases) as a collaborative one. ‘Use-oriented outputs’ include three sub-forms of boundary transaction: use-focused publications (publications which have a clear aim to reach an audience beyond the academic’s own scientific community); technological outputs (such as patents or software); and what I call ‘bridging concepts’ (which are grounded in science, but are designed to be understood and applied by non-experts – further discussion of ‘bridging concepts’, with examples, can be found under the analysis of Basic/Applied disciplines towards the end of Chapter 4). There are three sub-forms of ‘Boundary structures’: formal partnerships, such as medical schools which formally bring together university and NHS Trust, or formal university-industry consortia; economic structures such as spin-outs and technology transfer offices; and what I term here ‘transdisciplinary structures’, which cover all forms of problem-focused research centre and as well as other structures designed to link researchers either with other researchers or with users, provided that this linkage is not grounded (solely) on shared disciplinary background. Lastly, I found that staff, students and graduates could all play the role of ‘Boundary-spanner’.

|  |  |
| --- | --- |
| **Boundary transaction**  **(Coding frame)** | **Sub-forms (where applicable)** |
| Outreach | n/a |
| Collaboration | Co-authorship |
| Use-oriented outputs | Use-focused publications; Technological outputs; Bridging concepts |
| Boundary structures | Formal partnerships; Economic structures; Transdisciplinary structures |
| Boundary-spanners | Staff; Students/graduates |

Table 4. Main forms and sub-forms of boundary transaction

My decision to focus on boundary transactions as mechanisms through which boundaries can be potentially weakened or reproduced was theoretical, but the particular way in which I considered boundary transactions was partly informed by the empirical findings from the interpretive quantitative analysis (described above) derived from the typology data. Since analysis of the typology data found that overall, the sampled BoRs tended towards the reproduction of academic boundaries rather than their weakening, the main task was to understand this function of the identified boundary transactions.

After the coding of the boundary transactions as per Table 4, investigation involved reading and re-reading details related to the boundary transactions within the contexts of their BoRs to inductively seek patterns as to how boundary transactions are systematically contributing to this reproduction. Analysis at this stage did not seek to understand *variations between* different research contexts, but a general understanding of how boundary transactions played out in the context of academic STEMM research. Key characteristics of the boundary transactions to emerge were that they often contributed not only to a ‘third mission’ or ‘impact agenda’, but rather were linked up to other core missions such as promoting the teaching and training of students; similarly, rather than boundary transaction being targeted solely towards short-term results or immediate impacts, they were often part of longer-term relationships such that the ‘impactful’ results could not be disentangled from the longer term academic research contributions being made. This analytical step was therefore inductive, but not according to a ‘grounded’ or open-ended approach to qualitative theory-generation, as it was guided by (i) my theoretical understanding of the ways that boundary transactions can operate, and (ii) the goal of seeking explanations for the empirical findings from the typological data analysis.

As for the epistemological status of these boundary transactions and the findings from their analysis, boundary transactions are key causal mechanisms that operate just below the surface of the ‘empirical’ level captured by the typology data. They are not of course the *only* causal mechanisms associated with reproducing boundaries – for example, this focus on boundary transactions does not clarify how internal mechanisms of integration contribute to the reproduction of boundaries (B. R. Clark, 1983; Gumport, 2000; Parsons, 1967; Parsons & Platt, 1973). However, they do shed light on how boundaries are reproduced through research processes and practices, specifically on the role of research-related boundary transactions on academic boundary reproduction. From the critical realist perspective, this is an important theoretical step, addressing important *how* questions, but it does not yet address more underpinning *why* questions. Further in-depth investigation is required to begin to reach the underpinning structures shaping the observed functioning and effects of boundary transactions.

### Interpretive, explanatory investigation: underpinning structures and realities

The ideal of critical realist research is to reveal underpinning structures and realities which shape the phenomena studied, but whose existence and functioning transcends the specific cases or empirical objects and findings of a given study. The Bernsteinian lens adopted sees the shaping of academic boundaries as ultimately contingent on underpinning interplays of power and control. Some of the relevant sources of power will of course be associated with academia itself, but this may not be evenly distributed within academia, for example across different institutional and epistemic contexts. There will also be external forces of power acting upon academia and these may act upon academia in general ways or in ways which are mediated by different academic research contexts. In my study, academia’s power over its boundaries is indicated by its ‘boundedness’ in the typology analysis, which was interpreted as indicating the extent to which academia’s research activities and related boundary transactions were found to tend towards the reproduction of boundaries rather than their weakening. The goal is therefore to reveal and understand how power operates on academic research and research-related boundary transactions.

This stage of analysis therefore starts by aiming to explain empirical findings of the analysis of the typology data, specifically the observed variations across institutional and epistemic background. It draws ‘intensively’ (Danermark et al., 2002) on the interviews and analysis of the distribution of types of boundary transaction across different research contexts in order to seek explanations for variations between different institutional and epistemic contexts. Given the theoretical discussion in Chapter 2 highlighting the importance of ‘control’ over boundary transactions, the in-depth analysis here seeks patterns of different levels of control over transactions, as well as different forms of boundary transaction, as possible explanatory mechanisms. For example, it finds that researchers in ‘elite’ departmental contexts exhibit greater control over the knowledge production process than researchers in ‘non-elite’ contexts, with the latter more likely to share ownership over knowledge production with non-academic collaborators. As another example, it finds that Life scientists often cede significantly greater control than Formal scientists do to non-academic collaborators and users over the forms of boundary transaction. This occurs largely because the latter almost exclusively engage with non-academics who themselves have relevant doctoral qualifications and significant academic/scientific expertise and therefore are willing and able to accept forms of transaction which are relatively unchanged from their ‘natural’ academic form, for example advance technologies, patents or technical articles or other reports, whereas Life scientists often engage with actors who have a legitimate and relatively powerful stake in the topic, but whose non-scientific background means that they demand more user-friendly and less scientific forms of output such as lay-summaries and workshops, over which academics have inherently less control.

By focusing on the observed variations in the power and control over academic boundaries and boundary transactions exhibited by different contexts of academic research – such as more and less ‘prestigious’ departmental contexts, different branches of science, and more applied and more basic disciplinary contexts – the analysis is precise and evidence-based in terms of how it brings into focus the relevant underpinning sources of power. All claims regarding the significance of sources of power are (i) derived directly from the interview and documentary data and (ii) scrutinised and selected for their plausibility as explaining the empirical results of the interpretive quantitative analysis of the typology data. The sources of power emerging from this analysis therefore can be understood, from the critical realist perspective, as elements of underpinning structures whose operations shape and transcend the specific phenomena studied. The final section of the Analysis (Chapter 4), entitled *Towards an explanatory analysis*, focuses on how the data is suggestive of certain underpinning structures and sources of power shaping the boundary transactions and their role in boundary reproduction. The Discussion (Chapter 5) is dedicated primarily to elucidating and exploring the explanatory plausibility of the underpinning structures emerging from my analysis in relation to existing empirical and theoretical literature.

## Validity and generalisability

Maxwell (2013, pp. 126-129) describes eight strategies that may be employed to test validity of qualitative research: collecting *rich* data; being *intensively involved* in the data; soliciting *participant* *validation* of your interpretation of events; *intervening* in the social world; searching for *discrepant evidence*; *triangulation*; introducing an explicit *quantitative element*; *comparing cases*. Of these eight, I adopt elements of seven, with only *intervention* being inappropriate to this study due to my focus on past events.

*Intense involvement* with *rich* data is achieved by multiple re-readings of a range of data, including 345 documentary sources and “verbatim transcripts of the interviews” (Maxwell, 2013, p. 126). And, although I have not gone back to my participants to comment on my final report and conclusions, my strategy to interview participants *after* I had already developed a deep understanding of the BoRs through the documentary analysis incorporated an element of *participant validation* into the research design.

Moving onto *triangulation*:

“This involves using different methods as a check on one another, seeing if methods with different strengths and limitations all support a single conclusion. This strategy reduces the risk that your conclusions will reflect only the biases of a specific method, and allows ... a more secure understanding of the issues” (Maxwell, 2013, p. 102).

There are two elements of triangulation incorporated into my design. First, I triangulate various data sources to complete the coding in the first analytical stage. This adds validity to my interpretation of the BoRs and the ways in which academic boundaries were confronted and crossed in the process. Second, I triangulate descriptive statistics and in-depth qualitative analysis in the third analytical stage. This adds validity to my study since any posited explanations must be compatible with, and will be constrained by, two sets of findings.

Regarding the incorporation of a *quantitative element*,Maxwell (2013) explains that many qualitative designs already do include

“an implicit quantitative component. Any claim that a particular phenomenon is typical, rare, or prevalent in the setting or population studied, or that some behaviours or themes were more common than others, is an inherently quantitative claim, and requires some quantitative support.” (p. 128)

The use of descriptive statistics, of the kind I have employed, therefore

“does not make [the] study quantitative...; it simply makes explicit, and more precise, the implicitly quantitative nature of such claims...[,] allows you to test and support claims that are inherently quantitative, ... [and allows] for identifying and communicating the *diversity* of actions and perspectives in the settings and populations you study” (Maxwell, 2013, pp. 128-129, original emphasis).

An explicit and systematic quantitative element also helps to consider validity through the *search of discrepant data*:

“The appropriate use of numbers ... enables you to assess the *amount* of evidence in your data that bears on a particular conclusion or threat, such as how many discrepant instances exist and from how many sources they were obtained” (Maxwell, 2013, p. 128, original emphasis).

In addition to this quantitative element of validity via consideration of discrepant data, I actively consider the implications for my developing theories and explanations of discrepant data, highlighting them as a challenge to increase the nuance and complexity of my theoretical explanations rather than necessarily assuming them to be simply ‘anomalous’.

Lastly, although my design is not strictly one of a comparative case study, the maximum variation sampling strategy and the analytical strategies that I have adopted does introduce the potential for *comparison* as a validity test in the way Maxwell (2013, p. 129) describes. That is, the comparative element of the study helps the reliability and validity of any conclusions that rest on demonstrable similarities or differences within and between different categories (e.g. Applied and Basic research). This will become apparent in Chapters 4 and 5.

I do not claim that the particular events of my sampled BoRs are statistically generalisable to or representative of the wider population of STEMM academic research or of research which scored highly on the impact element of REF2014. However, I would argue that there is an analytical, theoretical generalisability to my findings and conclusions regarding the interplay between underpinning conditions and mechanisms within the structure of the higher education sector, and how these are likely to play out differently in different institutional and epistemic contexts. In the Conclusion (Chapter 6), I elaborate this discussion of the generalisability of the study with respect to specific findings.

I also want to acknowledge a potential criticism of my utilisation of the REF Impact data, particularly my decision to draw only from submissions achieving a high Impact rating. This is a practical decision for the sake of my study and should not be taken as a complete endorsement of the methods, definitions and processes employed by the REF assessment, many of which are contentious. A small but growing and intriguing, and highly insightful body of empirical literature has identified issues with the assessment of impact in the REF (Derrick & Samuel, 2016; Samuel & Derrick, 2015; Watermeyer & Chubb, 2018; Watermeyer & Hedgecoe, 2016). There are inevitably imperfections with any operationalised definition of a concept as broad and contested as ‘impact’. However, I believe the REF does have value as the result of a very large-scale peer review process which, among other things, yields a significant dataset about BoRs that have engaged with various non-academic sectors and actors in the pursuit of advancing their research agenda and realising non-academic impact. The alternative to my drawing from this dataset would have been to identify impactful research myself using some other criteria, which would constitute a significant project in itself.

## Ethics

Ethical issues touch every aspect of research design (Maxwell, 2013, p. 7). However, for the qualitative researcher, the “primary ethical obligation” (Maxwell, 2013, p. 92) is to the individual participants. Treatment and respect for my participants and their anonymity will therefore take up most of this section. However, I also consider broader ethical issues.

The topic of the research is not of a particularly sensitive nature on a personal level. Moreover, since I am interviewing participants as experts and professionals who have specific experience of conducting highly reputable academic research and of interacting with non-academic actors in order to achieve ‘impacts’ which have been recognised for their ‘reach’ and ‘significance’ (to borrow directly from the REF criteria terminology), it could be argued that the power balance between researcher and researched is somewhat reversed in this context (Burnham, Lutz, Grant, & Layton-Henry, 2008; Harvey, 2010; Stephens, 2010). This does not absolve me from ethical considerations, however. Maxwell (2013) suggests that a “good first step ... is to put yourself in their [the participant’s] position, and ask how you would feel if someone did to you what you are thinking of doing. ...[W]hat is a “research project” for you is always, to some degree, an intrusion into the lives of the participants in your study” (p. 92). I always bore this in mind and held my participants, their time, and their generosity with the highest respect. This started from my initial contact with the participants.

My first contact with participants was via letter posted to their institutional address, as found on institutional web profiles of the researcher, and I also enclosed the Information Sheet along with the letter (see Information Sheet and an example letter reproduced in Appendix B). This initial letter, as well as including generic information about my research and the interview, also explained to the participant that they had not been selected at random, but that I had contacted them as their specific BoR was being included in my study and that I had already read quite widely around their research related to the Impact Case Study to which it contributed. This letter explained that I would send a follow-up e-mail in order to make responding to my invitation easier for the participant. I also included my institutional postal address and e-mail address so that they could respond immediately if they preferred not to await my follow-up e-mail. The Information Sheet explained details such as what the interviews would cover, my strategy for protecting anonymity (see below), how their responses will be used, etc, as well as all other relevant information about the research and the ethics procedure that had been followed.

After a respondent agreed to be interviewed, we arranged a time that would be mutually convenient to meet. I asked for participants to make time for at least a one-hour interview if possible, although stressed that any time they could provide would be appreciated. In the event, the average interview length was just over one hour, most lasting between 55 to 85 minutes, the longest lasting 117 minutes, and the shortest only 25 minutes due to the very tight schedule of the participant. I gave participants the option of a phone call or an in-person meeting (always making it clear that I would be very willing to travel to their location, but without pushing either way in terms of a preferred mode of interview). Six interviews were arranged to be in-person and four via telephone, based on participant preferences. For the six in-person interviews, I travelled to the interviewees’ institution where we had an interview in a private office or meeting room booked by the participant. At the beginning of each interview I provided participants with the Information Sheet again and also a Consent Form (reproduced in Appendix B) which I asked them to read and sign, before signing it myself in their presence. For phone interviews, I called the participant from my home office to ensure privacy. Rather than provide phone interviewees with a physical Consent Form to sign, I read it out to them prior to starting the interview so that they could agree to each point. All signed consent forms were stored securely in my home study. All interviews were audio-recorded on a voice recording device following explicit signed and verbal consent. I conducted phone interviews with the loudspeaker function enabled so that the voice recorder could capture the participant’s end of the conversation without disturbance. Novick (2008) has noted that although there is some concern about the quality of telephone interviews, there is little evidence that they are of lower quality. My experience was that the telephone interviews were no less rich. Nor does my experience reflect the finding that telephone interviews tend to be shorter (Irvine, Drew, & Sainsbury, 2013). There was one exception to this, in which the participant had said in advance that he could only offer me a 25-minute interview due to time constraints, but the other three interviews averaged at around one hour, in line with the overall average. In terms of why participants opted for telephone interviews, one participant arranged the interview for a day they were working from home, and we conducted this interview as a video call, and the participant involved in the 25-minute interview presumably thought that such a short interaction was more appropriate over the phone (I did offer to travel to their institution). I am not sure why the other two participants opted for a telephone interview. I transcribed all interviews. All voice recordings and transcripts are saved as password-protected files on two home computers that only I have password access to. All recordings were deleted from the voice recorder after being transferred to the home computer.

My research presented particular challenges around protecting participant anonymity. Because of my significant research interest in the details of the conditions and collaborations associated with my sampled BoRs it was not feasible to omit these details entirely from the report. I therefore applied for and received ethical clearance not to anonymise my sampled institutions, departments and REF submissions. This means that anybody reading my report of the research could look up the sampled BoRs and quite easily find the public pages of the main researchers involved. To minimise the possibility of any of these individuals being identifiable from my report, I abstracted all quotations from their context. Therefore, when drawing on quotations to present my analytical findings, I do not state precisely which BoR the respondent relates to, but rather I only provide that contextual information which is pertinent to the point being made. For example, if exploring variations in responses from Basic and Applied research settings, I would cite any quotation as belonging to an ‘Applied researcher’ or ‘Basic researcher’. In addition, I also take care to edit out any details that would identify a given quote with a given BoR. For example, although a quote may refer to a specific research context, say, related to health, this would not reveal which BoR the respondent was from, since several BoRs take place within a health setting. This strategy was decided before contacting any potential participants and was explained to all participants in the Information Sheet and verbally as part of my procedure of obtaining informed consent.

### Demographic issues and ethics

I believe there is also a broader ethical issue affecting my study regarding recruitment demographics. My attempt to contact key researchers whose work had underpinned research recognised for its impact inevitably led me to contacting primarily senior researchers, mostly professors, and this in turn, meant I was more likely to be directed to male than female researchers. As Figure 7 shows, thirty-three of my thirty-nine invitations were sent to males, and twenty-five sent to professors. Moreover, the participation rate was higher amongst both males (27%) and professors (32%) than amongst females (17%) and non-professors (14%). In other words, males were 1.5 times more likely to respond positively than females, and professors more than twice as likely to respond positively as non-professors. The combined category of ‘male AND professor’ has an even higher response rate of 33%. By contrast the combinations of ‘male AND non-professor’ and of ‘female AND professor’ shows a response rate of only 1% and 0% respectively. My final sample of interviewees therefore included only two non-professors and only one female (who was one of the two non-professors).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Demographic information** | | **Invitations to participate** | **Acceptances** | **Participation Rate** |
| **Gender** | Male | 33 | 9 | 27% |
| Female | 6 | 1 | 17% |
| **Seniority** | Professor | 25 | 8 | 32% |
| Non-professor | 14 | 2 | 14% |
| **Gender & Seniority combined** | Male AND Professor | 24 | 8 | 33% |
| Male AND NOT Professor | 9 | 1 | 1% |
| Female AND Professor | 1 | 0 | 0% |
| Female AND NOT Professor | 5 | 1 | 20% |
| **Totals** | | **39** | **10** | **26%** |

Figure 7. Interview participant response rate and demographic information

I share this recruitment experience as I believe that such information is often obscured in reports of research methodologies, but if my experience is indicative of a wider tendency for female and less senior researchers to decline participation in research on academic work and life, then their experiences will be relatively absent from our collective knowledge. The higher education research community has an ethical duty to be critically reflexive about our collective knowledge, including the demographics of the respondents upon whose experiences and perceptions our knowledge is based.

# Chapter 4. Findings and Analysis

## Introduction

This chapter presents an analysis of the data. To recap, I purposefully sampled ten academic STEMM departments from across nine UK universities to achieve variation by epistemic and institutional context. Here, ‘epistemic context’ refers to the branch of science (life, natural, formal) and orientation of discipline (basic, applied), while ‘institutional context’ refers to the type of university (Boliver, 2015) and departmental rating (in REF2014). From these ten departments, I selected for analysis nineteen bodies of research (BoRs) which contributed to significant impact, as recognised in the results of REF2014.

The chapter is broken down into three significant sections. *Section one* (‘Boundaries and boundary transactions in the sampled research’)starts by presenting aggregate-level descriptive findings addressing whether the sampled research was found, on the whole, to tend towards the reproduction of academic boundaries or to its potential weakening. It also goes into more fine-grained detail by showing which kinds of research attributes/activities tend to be associated with reinforcing academic boundaries and which with crossing and potentially weakening them. It then breaks these results down by institutional and epistemic contexts such as prestige of department and branch of science. These sub-sections, then, highlight what can be gleaned from descriptive statistical analysis of the data generated from having plotted the n=19 bodies of research (BoRs) against the typology which, adapted from McNie et al. (2016), provided me with a tool for quantifying my interpretations of the ‘boundedness’ (see the ‘Analytical framework’ in Chapter 2 and ‘Analytical procedures’ in Chapter 2 for details) of the BoRs, which I took to be an indicator of the extent to which the sampled research was reproducing or potentially weakening academic boundaries. *Section one* then develops this analysis by presenting quantitative data about the role of boundary transactions in the complex process of reinforcing and crossing academic boundaries. This shows that boundary transactions can act as mechanisms in both directions (reproduction and weakening), sometimes simultaneously, and highlights the theoretical point that boundary-crossing is at once a necessary part of the process of reproducing boundaries *and* is a major mechanism through which boundaries may be weakened.

*Section two* (‘In-depth illustrative analysis’) of this chapter provides an extended, in-depth analysis of *three* of the n=19 BoRs on which I conducted the analysis. This serves a few purposes. It gives the reader an in-depth insight into the processes through which I read, interpreted and analysed my data, which primarily consisted of ~350 documentary materials and webpages and was supplemented by ten in-depth interviews with STEMM academics. More specifically, it explains and justifies my decisions associated with coding/plotting these BoRs against the typology. This is important, since, when I go into detail about how the typological data varied by institutional and epistemic context, this analysis will mainly only be able to focus on *what* was found, rather than *how* it was found. The three illustrations therefore serve to make transparent what would otherwise be obscured. They also allow me to start to draw out broader interpretations and arguments about the questions of how boundary-crossing interactions impact the reproduction of academic boundaries, and the role that different aspects of the research process have in the shaping and reshaping of academic boundaries. For example, they allow me to show in qualitative detail how the five forms of ‘boundary-transaction’ can potentially operate to weaken or to reproduce academic boundaries.

In *section three* (‘Towards an explanatory analysis’), I go into further detail about each of the key contextual dimensions of interest – ‘departmental status’, ‘branch of science’ and ‘orientation of the discipline’. I draw out variations in the boundary transactions and overall manner and extent of boundary crossing amongst these dimensions. This involves analysis of the frequency of boundary transactions and, in particular, analysis of the variation across these dimensions in the quantitative data generated by the typology analysis. I also draw heavily from the qualitative interview data to provide further insight into the underpinning causes of the observed variations. The analysis is geared towards positing explanations for the observed variations. *Section three* posits the following three broad elements that explain both the overall experience of academic boundaries and boundary transactions of the researchers in my sample, as well as variations within them. *First*, a key factor in influencing whether the boundary transactions associated with ‘impactful’ academic research is the prior power held by the academic unit (i.e. the individual, research centre, department, institution). This manifests most clearly when comparing the results in departments with differing ‘statuses’ or ‘reputations’, but I argue that it has more general implications.

*A second* key factor revealed relates to what kinds of actors are interacted with in the process of ‘transacting’ across boundaries. In some cases, boundary transactions can be focused on non-academics who themselves have a relatively strong academic identity – for example, they have PhDs and have maintained strong links to academia, and their job is aided by staying in touch with, applying and occasionally collaborating on academic research. Such transactions pose far fewer challenges to boundaries and transactions across them than cases where academics have to interact with non-experts. Typically, this involves interacting with policy actors and often others, since in most cases, issues of policy are also issues of contention between different groups, all of whom have a stake in the academic research and its interpretation. Such transactions encourage academics to develop a strong sense of academic identity, as this is crucial to maintain objectivity and legitimacy in such contested spaces. This factor plays out most strongly in the dimension of ‘branch of science’, where Formal scientists typically experience the former, more simple boundary transactions, and Life scientists the more complex transactions, and Natural scientists falling somewhere in the middle of these two extremes.

*The third* main factor revealed relates to the way in which academic research intersects with broad systems of knowledge. I have identified three main systems of knowledge acting upon and influencing my sampled research. *The first* is internal and relates to the drive within academia to bring all aspects of the natural world into the academic domain. This promotes a very ‘bounded’ mode of research, and the norm is that boundary transactions take the form of traditional academic outputs such as journal articles. This first system of knowledge is mostly exemplified by the research from Basic/Applied disciplines, in my sample. *The second* is well-characterised by the ‘mode 2’ system of knowledge production. This is a very ‘unbounded’ mode of research and arguably tends towards a ‘post-academic’ science. It is typical of the research in my sample from Applied disciplines. *The third* and last main system is probably best well-described by the concept of a ‘technoscientific’ system. Here, powerful political, commercial and military institutions use their resources to mobilise the knowledge system, and this inevitably brings universities into this system. This most commonly impacts upon research sampled from the Basic disciplines, due to a synergy between the technologies which satisfy both the interests of these powerful actors and the scientific curiosity of Basic scientists.

## Boundaries and boundary transactions in the sampled research

### Analysis of the typology data

#### Evidence-based classification of the multi-dimensional activities/attributes of research into three ‘research dimensions’

I plotted the n=19 BoRs against a multi-dimensional typology adapted from McNie et al. (2016). The typology comprises a 1-5 scale of the ‘boundedness’ (from ‘very bounded’ to ‘very unbounded’) of a given BoR on fifteen attributes/activities associated with research. Plotting each BoR against the typology therefore provided me with a way of organising and quantifying my interpretation of the extent to which sampled research and its related boundary transactions tended towards the reproduction of academic boundaries (see the ‘Methodology, Chapter 3 for more details). Table 5 shows the total values for the fifteen attributes/activities from the typology. These are the average values for all attributes/activities as coded against each of the n=19 BoRs. It shows that the activities/attributes can be divided into three distinct sub-sets or groupings. One grouping receives consistently *high* values on the typology and has an average value above 3 (which is the mid-point on the 1-5 spectrum). Another grouping has consistently *low* values, averaging below 2. The third group is the largest and includes those attributes/activities which fall between 2 and 3. I argue that these three classifications of research dimension, which I call the ‘social context’ attributes, the ‘intermediate(ry)’ attributes and the ‘knowledge content’ attributes, reflect a reality about the nature of the different activities/attributes of research (or, at least, the research in my sample). I briefly summarise this interpretation below and elaborate upon it further in *section two* (‘In-depth illustrative analysis’) of this chapter.

|  |  |  |
| --- | --- | --- |
| **Attribute/activity** | **Total** | **Classification (research dimension)** |
| Goals | **3.86** | **‘Social context’** |
| Relevance | **3.63** |
| Evaluation | **3.4** |
| Outputs & outcomes | **3.28** |
| Uncertainty | **2.81** | **‘Intermediate(ry)’** |
| Knowledge Exchange | **2.58** |
| Accessibility | **2.53** |
| Boundary Management | **2.42** |
| Network Participation | **2.33** |
| Flexibility | **2.3** |
| Disciplinary Focus | **2.3** |
| Social Capital | **2.18** |
| Expertise | **1.68** | **‘Knowledge content’** |
| Learning | **1.56** |
| Human Capital | **1.49** |
| **Overall average** | **2.56** |  |

Table 5. Average values for the fifteen attributes

Social context

First, the attributes in the highest (3<*value*) range (goals, relevance, evaluation and outputs & outcomes) includes those attributes which, in my sampled research, tended to involve significant engagement with or influence from the *social context* beyond academic boundaries. It is primarily through them that the social context influenced the academic research in my sample. For example, the goals of my sampled research are often informed and, in some cases, directly guided by issues arising in the social context beyond academia. Accordingly, the research aims at yielding outputs and outcomes of relevance to these contexts, and to a large extent the research is considered a success to the extent that it achieves this relevance and ‘impact’. I refer to these as the ‘social context’ attributes.

Knowledge content

By contrast, the low value range (1<*value*<2) includes attributes/activities which, in my sampled research, tended to remain strongly within academic boundaries (expertise, learning and human capital). I argue that they played a significant role in reproducing academic boundaries largely by maintaining academic authority over the *knowledge content* of academic research. This is because it remains the case that what can be learned from academic research is highly technical, and typically requires significant levels of scientific expertise and academic qualifications in order to fully understand it and to be able to produce it, albeit that my sample also includes several instances where other types of expertise and human capital were drawn upon in the research process (some examples of which will be discussed below). I classify these as the ‘knowledge content’ attributes/activities.

Intermediate(ry)

In between these is the mid-range value grouping (2<*value*<3). This is the largest group of attributes and activities (uncertainty, knowledge exchange, accessibility, boundary management, network participation, flexibility, disciplinary focus and social capital). I will argue that in the sampled research, the attributes and activities in this range mediate between the social context, which has significant influence over the goals and evaluative criteria of academic research, and the knowledge content, authority over which lies within academia. In doing so, these attributes and activities mediate the interaction between academia and wider society. This means that, while they are important ways in which academia contributes and responds to wider society, they are also key sites for struggle over the direction of academic research. For example, although some level of knowledge exchange, flexibility and accessibility is essential for any university wishing to be seen as relevant to society, the interesting issue is how much, on what terms, and with what kinds of external actors is knowledge exchanged, and flexibility and accessibility offered? I refer to the attributes and activities in this mid-value range as ‘intermediate(ary)’ or ‘mediating’ attributes/activities.

Figure 8 presents a simplified model of the attributes and activities under the ‘intermediate(ry)’ classification/dimension. Later in this chapter I will discuss the operation of all fifteen activities and attributes in the context of three illustrative BoRs.

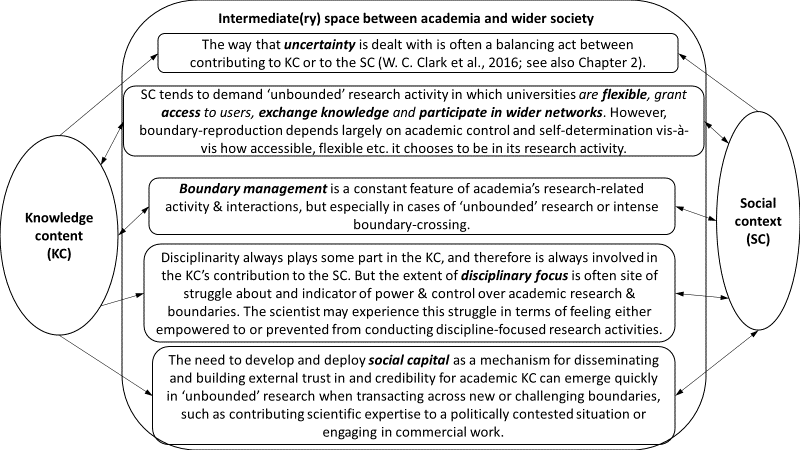


Figure 8. Relationship between the three classifications/research dimensions: the role of ‘intermediary’ activities and attributes

#### Analysis of the ‘contextual dimensions’ (institutional and epistemic context)

Following on from the above discussion, Table 6 shows the average typology values broken down by the different contextual dimensions, that is, different institutional and epistemic contexts, that I am interested in exploring. These contextual dimensions include different institutional contexts by prestige of department (‘elite’, ‘more prestigious’ and ‘less prestigious’), branch of science (Life, Natural and Basic sciences) and orientation of science (‘applied’, ‘basic’ and ‘basic/applied’, this latter denoting disciplines which are inherently ‘use-inspired’ *and* focused on producing basic knowledge). Table 6 uses shading to demarcate the data for the three dimensions, with departmental prestige at the top, branch of science presented in the middle, and orientation at the bottom. For each, it breaks the data down by the three dimensions of research discussed above (‘social context’, ‘intermediary’ and ‘knowledge content’) and presents the different categories in ascending order of *average* typology value. So, in the dimension of departmental prestige, the ‘elite’ contexts have the lowest overall value (2.4), followed by ‘more prestigious’ contexts (2.53) and finally the highest value (2.69) for ‘less prestigious’ contexts.

Table 6 suggests, therefore, that research which is (i) based in ‘elite’ institutional contexts, and which is based in a (ii) Life science and (iii) basic/applied discipline, is likely to have a low overall typology value – that is, such research is typically ‘bounded’ and likely to promote the reproduction of academic boundaries. This is less true for other combinations of research contexts, particularly that which is based in (i) ‘less prestigious’ departments, (ii) a Formal science and (iii) applied disciplines.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Context dimension | Category | Social Context | Intermediary | Knowledge Content | **Average typology value** |
| Institutional context (departmental prestige) | Elite | 3.61 | 2.15 | 1.45 | **2.4** |
| ‘More’ prestigious | 3.4 | 2.46 | 1.54 | **2.53** |
| ‘Less’ prestigious | 3.49 | 2.63 | 1.78 | **2.69** |
| Epistemic context (branch of science) | Life | 3.17 | 2.42 | 1.72 | **2.48** |
| Natural | 3.44 | 2.39 | 1.65 | **2.52** |
| Formal | 3.92 | 2.46 | 1.46 | **2.64** |
| Epistemic context (orientation of discipline) | Basic/Applied | 3.06 | 2.3 | 1.78 | **2.4** |
| Basic | 3.24 | 2.37 | 1.52 | **2.43** |
| Applied | 3.95 | 2.52 | 1.55 | **2.71** |

Table 6. Typology values (averages) by contextual dimension (institutional and epistemic context) and research practice dimensions ('social context', 'knowledge content' and 'intermediary' attributes/activities)

It is worth highlighting that *all nine* categories (the nine rows in Table 6) have a total value of less than 3. I note this because 3 is the mid-point on the typology’s spectrum, and therefore this result suggests that (‘impactful’) academic research will typically tend more towards the reproduction of academic boundaries than their weakening, regardless of context. But there are important variations. The above paragraph has already highlighted that within each dimension, there is variation in the total values, which range from 2.4 (for ‘elite’ and ‘basic/applied’) up to 2.71 (for ‘applied’). However, a more detailed look at the table’s data is suggestive of further interesting variations in the complex ways in which boundary processes play out. I will draw these out later in the chapter as I go into detail about each of the contextual dimensions. But briefly, the table suggests potentially interesting variations in the relationships *between* the different research dimensions.

For example, there appears to be an inverse relationship between ‘social context’ and ‘knowledge content’ values. In the departmental dimension, ‘elite’ contexts display the highest ‘social context’ value (3.61) but the lowest ‘knowledge content’ value (1.45); the same is true in the branch of science dimension, where formal sciences display the highest ‘social context’ value (3.92) and the lowest ‘knowledge content’ value (1.46) and life sciences displaying the converse, the lowest ‘social context’ value (3.17) and the highest ‘knowledge content’ value (1.72); lastly, applied sciences exhibit the highest ‘social context’ value across any dimension (3.92) with a low (although not quite the lowest) value on ‘knowledge content’ (1.55). What this suggests is that research which is more ‘unbounded’ in its relation to the social context balances this by being more ‘bounded’ in terms of their ownership and control over the knowledge content of their research; or, alternatively, perhaps having strong control over the knowledge content gives some license to engage more extensively (or to be ‘unbounded’) in the social context. There may be other possible reasons and interpretations, and these are discussed in greater detail in later sections of this chapter, where I give an in-depth illustration of three of the sampled bodies of research (BoRs), and then break down the analysis by the three contextual dimensions, which allows me to shed explanatory light on variations in the ‘boundedness’ of research in my sample.

### The role of boundary transactions

#### Frequency of the five forms of boundary transaction

Table 7 presents the frequency of boundary transactions[[18]](#footnote-18). Most of the nineteen sampled BoRs exhibited ‘boundary structures’ (16 BoRs). This suggests that an important part of most STEMM departments’ approach to facilitating and regulating their engagement beyond academic boundaries is through the construction of boundary structures, such as problem-focused research centres, technology transfer offices and academic spin-out companies. This high frequency is likely to be because, as discussed earlier, organisational structures, particularly outward-facing ones, are not only forms of boundary transaction in their own right, but are also likely to promote other kinds of boundary transaction.

Next, ‘boundary-spanners’ (13 BoRs) were exhibited in over two-thirds of the sampled BoRs. This suggests the importance of individuals who have been able to act as brokers and bridges between academic and non-academic contexts, whether they be doctoral graduates who move to industry and maintain academic links, academics who spend a brief period in industry, or industry scientists who come to take up academic posts.

Third is ‘outreach’ (12 BoRs). Table 7 in fact somewhat undercounts this form of boundary transaction, since my coding of outreach only counted for those cases where the identified outreach *was not also* an instance of one of the other boundary transaction types – outreach often underpins and subtly leads to more intensive forms of boundary transaction but Table 7 does not fully capture this.

Just over half of the sampled BoRs exhibited the remaining two transaction types, ‘collaboration’ (co-authorship) and ‘user-focused outputs’ (11 BoRs each). Collaboration (co-authorship) and user-focused outputs are relatively intensive forms of boundary transaction. They involve developing close relationships or close lines of communication with potential users or other knowledge-producers closer to the context of application, and therefore are more likely to incur non-negligible transaction costs. They are therefore unsurprisingly less frequent.

|  |  |
| --- | --- |
| **Boundary transaction form** | **Frequency (no. of BoRs exhibiting transaction)** |
| Boundary structure | 16 |
| Boundary-spanner | 13 |
| Outreach | 12 |
| Collaboration (co-authorship) | 11 |
| User-focused output | 11 |

Table 7. No. of BoRs exhibiting each form of boundary transaction

Given the theoretical discussion of boundary transactions (Chapter 2) and the empirical findings from the typology analysis presented above, I am interested in the way that boundary transactions might contribute not only to the crossing of boundaries, but also as a boundary-regulating, and potentially boundary-reproducing mechanism. The *In-depth illustrative analysis* below will provide some examples of these boundary transactions ‘in action’ and therefore shed light on this process. However, some aggregate level findings also provide an indication. I will focus on two main issues pertinent to the boundary transactions – first the issue of *when* in the research process boundary transactions occurred, and second the issue of what precise functions each boundary transaction played, for example whether the boundary transactions were focused only on the outward-facing ‘third mission’ of universities, or whether the boundary transactions could also simultaneously advance the universities’ traditional ‘missions’ of disciplinary research and teaching.

#### The timing of boundary transactions (by ‘phase’ of research)

Regarding the first issue, that of the timing or ‘phase’ of research when boundary transactions came into action, it might be expected that boundary transactions, particularly ‘collaboration’ and ‘use-focused output’, become more important later in the research process. This is because the research would be more likely, at this stage, to be ready for dissemination to users, and likely to be a less uncertain and risky project from the perspective of non-academic collaborators. However, my analysis is able to provide evidence that this is not necessarily the case. As explained in the Methodology (Chapter 3), I broke down each BoR into three ‘phases’ for the analytical procedure of coding/plotting each BoR against McNie et al.’s (2016) 1-5 spectrum of the extent of boundary-crossing engagement with users. Each ‘phase’ demarcated a significant temporal landmark in the research, for example, when a key finding led to a change of direction or focus, or a new important collaboration commenced, or a new research grant enabled the research to progress, etc. In general, as might be expected, the phases became more ‘user-focused’ as they went on, and this indeed was the case in my sample of research. This is reflected in the average values of the three phases after I coded the sampled BoRs against McNie et al.’s (2016) typology, which involved plotting BoRs against their 1-5 spectrum for coding the extent of user-focused boundary-crossing exhibited by a given BoR (see Table 8). As Table 8 shows, the average value at Phase 1 across all n=19 BoRs was 2.11, which was quite significantly lower than the average of 2.64 at Phase 2, which was lower still than the average of 2.92 at Phase 3[[19]](#footnote-19).

|  |  |  |  |
| --- | --- | --- | --- |
|  | Phase 1 | Phase 2 | Phase 3 |
| Average typology value | 2.11 | 2.64 | 2.92 |

Table 8. Average typology values by 'Phase'

Informed by the aggregate-level finding in Table 8 then, Figure 9 (below) is able to show that non-academic co-authors whose role is close to the context of application were almost just as involved in the early stages of the sampled research as they were in the latter stages, even though (as Table 8 suggests) the early stages were quite significantly less focused on the context of use. Eight BoRs involved co-authorship with a non-academic collaborator at Phase 1, with the same number at Phase 2, and only a slight increase of nine at Phase 3. Figure 9 also shows the same pattern for the boundary transaction type of ‘use-focused outputs’: six outputs came at Phase 1, six at Phase 2 and seven at Phase 3.

Figure 9. Frequency of 'co-authorship’ and ‘use-focused outputs’ across the three 'Phases' of the sampled BoRs

In sum, boundary-crossing transactions in the forms of co-authoring research with non-academics and producing outputs of direct relevance to users were important mechanisms for the realisation of ‘impact’ grounded on academic research. But this does not mean that these transactions only occurred when the research was close to its final application. Rather, in many cases, these forms of boundary-transaction occurred at earlier, more fundamental, and les certain phases of research. There are a couple of preliminary possible interpretations of this in terms of the implications for academic boundaries. The first is that there is a quite fundamental reshaping and weakening of academic boundaries such that there is a merging of interests, goals and activities with other, non-academic sectors. The other is that engaging in such boundary transactions at these earlier and more fundamental phases of research reinforces universities’ position as society’s central knowledge-producing institution, thereby reinforcing its distinctive value and identity, and thereby contributing to the reproduction of its boundaries. I will pursue both these possibilities in later sections and chapters and ultimately argue that, in fact, these two interpretations are not incompatible, and both represent part of the reality.

#### The multiple functions of boundary transactions

According to the earlier theoretical discussion, boundary transactions are not just about crossing boundaries and serving wider society. Boundary transactions do involve crossing boundaries, and as such they are potential opportunities for external interest groups to take control over the work and challenge the authority of the ‘bounded’ entity (i.e. academia). But boundary transactions are also about regulating and potentially reinforcing and thereby reproducing boundaries. As such it is worth considering evidence that the boundary transactions in my sampled research are acting in this way. Figure 10 shows this in relation to the other three forms of boundary transaction, ‘boundary structure’, ‘boundary-spanner’ and ‘outreach’ (having discussed ‘collaboration’ and ‘use-focused outputs’ above).

Figure 10. Percentage of selected boundary transactions contributing to different university missions

Specifically, Figure 10 shows the percentage of ‘boundary structures’, ‘boundary-spanners’ and ‘outreach’ activities which functioned to advance the university’s other core missions of research and teaching, as well as their ‘third’ mission. The point at this stage is not to extensively compare these three forms of boundary transaction but simply highlight that it is normal, at least in my sampled research, for boundary transactions to have multiple functions: only 10% of the ‘boundary structures’ associated with my sampled research had a sole ‘third’ mission focus, with almost 90% also contributing directly to core departmental research and/or their teaching/training mission; the percentage was somewhat higher amongst ‘boundary-spanners’, but still low, at just over 20%; and even the highest percentage, that for ‘outreach’, is only just over 50%. In sum, the boundary transactions in my sampled research were not only involved crossing boundaries to provide benefits for wider society, but directly contributed to those missions which constitute the university’s distinct and “bounded” (Bernstein, 2000, p. 99) institutional identity.

### Summary of academic boundaries and boundary transactions in the sampled research

*Section one* of this chapter has presented a descriptive statistical analysis of the data generated from the typology. This allowed me to show not only that the overall tendency of the sampled research was towards the reproduction of academic boundaries rather than its weakening, but also shed light on one particular aspects (activities & attributes) of research are the main mechanisms through which academic research contributes to this reproduction. I developed this analysis by presenting quantitative data about the role of boundary transactions, given the role (according to the theoretical ‘boundary lens’ adopted) of boundary transactions in the complex process of regulating (academic) boundaries. This analysis began to show, albeit at an aggregate level rather than in a qualitatively and contextually rich way, that boundary transactions can act as mechanisms in both directions , towards reproduction and weakening, sometimes simultaneously, but that on balance, the boundary transactions associated with the sampled research were successful in regulating the boundary and therefore contributing to boundary reproduction.

The following section will provide deeper insights into these processes by presenting more qualitative and contextual detail about boundary transactions in context.

## In-depth illustrative analysis: three bodies of research (BoRs)

This section provides illustrative in-depth analyses of three of the nineteen BoRs. This shows how the forms of boundary transaction operated in practice. It also shows how I assessed and coded my sampled research on the 1-5 spectrum against the typology’s (McNie et al.’s, 2016) fifteen activities/attributes of research. I will organise the discussion of each BoR under three sub-headings corresponding to the above classification of attributes/activities: ‘social context’, ‘knowledge content’ and ‘intermediate(ry)’. For this purpose, I select the BoR which received the highest overall value on the typology (based on an average of all fifteen of its activities’/attributes’ values), the BoR receiving the lowest value, and the middle-value BoR. As Table 9 shows, this puts forward BoR11.1 (total/average value of 3.38), BoR5 (2.49) and BoR4.2 (1.76). That is, I judged that the BoR ‘Clinical outcome modelling saves lives’ to display, overall, the greatest extent of boundary-crossing, and ‘Informing MDMA policy’ to display the least, while ‘Sea Mammal Research & Impact’ received the middle-value among the nineteen BoRs.

|  |  |
| --- | --- |
| **BoR (no. and title)** | Total typology value |
| 11.1 ‘Clinical outcome modelling saves lives’ | 3.38 |
| 7.2 ‘New Paths to Mangrove Conservation’ | 3.36 |
| 11.2 ‘Improved mobility and quality of life for children with disabilities’ | 3.13 |
| 14.2 ‘Management of discolouration in drinking water distribution systems’ | 2.82 |
| 1.2 ‘Treating Heart Failure’ | 2.67 |
| 8.2 ‘Mercury Capture Technology for the Global Petroleum Industry’ | 2.76 |
| 8.3 ‘Practical Raman Chemical Analysis for Forensic Applications’ | 2.76 |
| 13.2 ‘Topical oxygen therapy for wound healing’ | 2.73 |
| 1.1 ‘Diagnosing and Treating Cardiovascular Conditions’ | 2.58 |
| 5 ‘Sea Mammal Research & Impact’ | 2.49 |
| 10.2 ‘Quantification of the benefits of statins’ | 2.40 |
| 10.1 ‘Monitoring Groundwater Pollution’ | 2.36 |
| 8.1 ‘Biocatalysts for Industrial and Medical Applications’ | 2.33 |
| 4.1 ‘Informing Smoking Policy’ | 2.31 |
| 9 ‘Astronomical Research and Instrumentation’ | 2.24 |
| 13.1 ‘High-performance nanostructured-steel armour’ | 2.20 |
| 7.1 ‘Defining and Sustaining Healthy Seas’ | 2.18 |
| 14.1 ‘Managing full scale dynamic performance of civil infrastructure’ | 2.13 |
| 4.2 ‘Informing MDMA Policy’ | 1.76 |
| **Sample average** | **2.56** |

Table 9. BoR overall typology values

This section will therefore serve to (i) give the reader insight into the way in which I read and interpreted the sampled research (the nineteen BoRs), in particular how this interpretation translated into decision about how to code (or ‘plot’) each BoR against the typology, and (ii) highlight the main tendencies and variations in the ways in which boundary transactions operate and in which the multi-dimensional activities/attributes of academic STEMM research tend towards crossing or reproducing academic boundaries.

### Illustrative case 1. ‘Unbounded’ research (BoR11.1)

BoR11.1, ‘Clinical outcome modelling saves lives’, is based on research in the field of computer science and informatics at the University of Portsmouth, Faculty of Technology, Centre for Healthcare Modelling and Informatics (CHMI). CHMI is an academic ‘boundary structure’ bringing together academic and non-academic experts, academics with different backgrounds and expertise, and NHS staff with different functions, including researchers as well as clinical practitioners. In terms of the institutional and epistemic context of BoR11.1, it can be characterised, within my thesis, as an ‘applied’, ‘formal’ science in a ‘less prestigious’ departmental context. Table 10 presents BoR11.1’s typology values by the three ‘research dimensions’ derived earlier (‘social context’, ‘intermediary’ and ‘knowledge content’) and, for comparison, shows how these compare with other research sharing its contextual characteristics (applied, formal, less prestigious) and with the overall sample average. This shows that BoR11.1 has a very high social context value relative to others sharing its characteristics, and a somewhat higher knowledge context value. But BoR11.1 mainly stands out in terms of having a very high ‘intermediary’ value. I will explore each of these three research dimensions in turn below.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Social Context | Intermediary | Knowledge Content |
| **BoR11.1** *(applied, formal, ‘less prestigious’ dept.)* | **4.5** | **3.38** | **1.89** |
| ‘Applied’ average | 3.95 | 2.52 | 1.55 |
| ‘Formal’ average | 3.92 | 2.46 | 1.46 |
| ‘Less prestigious’ average | 3.49 | 2.63 | 1.78 |
| **Sample average** | **3.54** | **2.43** | **1.58** |

Table 10. BoR11.1 typology values by 'research dimension' (with comparator values)

#### ‘Social context’ values (goals, relevance, evaluation, outputs & outcomes)

Phase 1. (An auditing system for comparing surgical outcomes across hospitals)  
In the 1980s, there was significant interest in introducing new auditing and benchmarking procedures into surgical practices in order to enable greater comparison between hospitals. The idea was that this would enable ‘good practice’ to be identified and would drive up standards and results of surgical outcomes by encouraging competition between hospitals.

This created a demand for research into the factors likely to affect surgical outcomes, so that they could be accounted for in benchmarking and standardisation. For example, any benchmarking tool had to be able to account for the fact that negative surgical outcomes are not just a factor of the individual hospital or surgeon, but are also dependent upon other factors, significantly patient characteristics such as age and medical history.

Some such audit systems did already exist. However, a collaborative team of researchers which brought together medical doctors, medical physicists, and statisticians from Portsmouth NHS Trust and the University of Portsmouth’s CHMI (the ‘Portsmouth Team’), identified significant limitations in existing audit systems. For example, the most widely accepted system at that time over-predicted the average death rate of surgery, and did so to different extents depending on patient characteristics, meaning the benchmarks were unreliable. At ‘Phase 1’ then, the Portsmouth Team were motivated to conduct new and more systematic data-collection and statistical refinement in order to improve the reliability of existing systems’ formula and predictive capabilities.

When it came to plotting Phase 1of this BoR against the typology (see Table 11 summary), I judged the ‘goals’ of the research to be very much grounded in the real-world context of medical practice, rather than driven by scientific objectives such as disciplinary and theoretical expansion. I therefore gave a value of 5 on the typology for ‘goals’. However, for the ‘relevance’ of the research I gave a value of 4, since, although driven by the goal of maximising relevance for the specific purposes of benchmarking and comparison, the results of the research potentially had broader scientific relevance.

Similarly, I gave a 4 for the ‘outputs/outcomes’ of the research. Again, although the prime output was a tool for use in practice, contribution to the academic literature was a significant part of that process, and therefore I chose not to give the highest value of 5. This was even more the case for ‘evaluation and effectiveness’, for which I gave a value of 3. Ultimately, the effectiveness of such a tool will be evaluated in the context of application. However, at Phase 1, more traditional scientific forms of evaluation were also essential, that is, evaluation by the scholarly community who would review and accept the rigour and value of the contribution as presented in scientific journals. Table 11 summarises these values.

|  |  |
| --- | --- |
| **Attribute/activity** | **Value (Phase 1)** |
| Goals | 5 |
| Relevance | 4 |
| Evaluation | 3 |
| Outputs | 4 |

Table 11. BoR11.1 'social context' values - Phase 1

Phase 2. (Developing an Early Warning System (EWS) for real-time clinical care)  
For the following decade, into the early 2000s, the collaboration between the NHS and the University that made up the Portsmouth Team was further consolidated with the appointment of one NHS medical physicist as Professor of Health Informatics at CHMI. This ‘boundary-spanner’ became the main link between the partner institutions and led the development of what I have demarcated as ‘Phase 2’. The research advanced in two main directions. First, it broadened in scope by applying its model to general medicine cases rather than only to surgery outcomes. Second, it targeted being more than just a benchmarking and comparison tool, and aimed to become of direct real-time relevance in clinical contexts. The aim was to produce an algorithm based on a combination of patients’ biographical data and vital signs data that would generate a so-called ‘early warning score’ (EWS). The EWS would identify and rank patients most at-risk of immediate deterioration and therefore in need of extra monitoring and care.

At Phase 2, then, I rated the ‘goal’ as 5 (as I did for Phase 1). However, I increased the value of ‘relevance’ (5), ‘outputs & outcomes’ (5) and ‘evaluation & effectiveness’ (4) (see Table 12). These values reflect the more immediate relevance and applicability of the outputs of this phase of the research, and also reflecting that the Portsmouth Team considered this phase of research to be a success to the extent that it was valued by clinical practitioners. Table 12 summarises the values for Phase 2 (also showing Phase 1 for comparison).

|  |  |  |
| --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** |
| Goals | 5 | 5 |
| Relevance | 4 | 5 |
| Evaluation | 3 | 4 |
| Outputs | 4 | 5 |

Table 12. BoR11.1 'social context' values – Phases 1 & 2

Phase 3. (Developing and disseminating the EWS for routine hospital use)  
Phase 3 demarcates the next steps taken by the Portsmouth Team to develop and disseminate their EWS into a scalable system for widespread application throughout an entire hospital and, potentially, the NHS more generally. This required reaching out (‘outreach’) to two new kinds of partner. The first, starting in the mid-2000s, was with private sector specialists in medical informatics. This partnership centred around developing a commercial product to digitise the process of inputting the patient data and refining the algorithm which generates the EWS, as well as digitally disseminating the EWS to relevant staff around the hospital. At the time of the REF submission, the company had sold the resultant technology to more than 20 hospitals globally. Second, the Portsmouth Team also wanted to make a non-commercial version of their EWS available for free to the NHS. The team worked with the Royal College of Physicians (RCP) in order to deliver this. At the time of the REF submission, the RCP had recommended for the NHS to fully adopt the Team’s EWS, and it had already been adopted in other countries.

As summarised in Table 13, I rated the four attributes/activities the same at Phase 3 as I did for Phase 2, as I judged the Phase 3 goals, relevance, outputs & outcomes and evaluation & effectiveness to be direct continuations of these activities/attributes at Phase 2.

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** | **Value (Phase 3)** |
| Goals | 5 | 5 | 5 |
| Relevance | 4 | 5 | 5 |
| Evaluation | 3 | 4 | 4 |
| Outputs | 4 | 5 | 5 |

Table 13. BoR11.1 'social context' values – Phases 1-3

#### ‘Knowledge content’ values (expertise, learning, human capital)

Phase 1. (An auditing system for comparing surgical outcomes across hospitals)  
Table 14 shows the ‘knowledge content’ values, including ‘expertise’, ‘learning’ and ‘human capital’, at Phase 1 of BoR11.1. I coded the ‘human capital’ attribute as 1, reflecting that importance of the “hard skills” possessed by the researchers involved, all of whom have doctorates and “rigorous training in specialized skills” (McNie et al., 2016, p. 890). However, I coded ‘expertise’ as 2, because the importance of certain practitioner expertise, i.e. that of clinical practitioners, was also “needed to help inform” the research thanks to their “proximity to the problem” (ibid., p. 887). For ‘learning’, I coded a 1. This is because, although the ultimate goal of the research was to inform “practical” learning, normally associated with a higher value, at this stage, the main “ways in which the research outputs change[d] the knowledge system” were through the “explicit knowledge” codified in protocols and academic journals (ibid., p. 888).

|  |  |
| --- | --- |
| **Attribute/activity** | **Value (Phase 1)** |
| Expertise | 2 |
| Learning | 1 |
| Human Capital | 1 |

Table 14. BoR11.1 'knowledge content' values - Phase 1

Phase 2. (Developing an Early Warning System (EWS) for real-time clinical care)  
At Phase 2, the ‘human capital’ and ‘expertise’ attributes did not change, and were coded again at 1 and 2, respectively. But there was a slight change in the nature of the ‘learning’ which resulted. Although at this stage the most significant “change in the knowledge system” (ibid., p. 888) was still able to be captured in codified forms, there was more of a “practical” element of learning, because the trial implantation of an EWS to impact real-time clinical practice also involved “changing behaviour” (ibid., p. 888) of a wider range of hospital staff, including those not involved in the knowledge production. I therefore increased this value to a 2. Table 15 summarises these values.

|  |  |  |
| --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** |
| Expertise | 2 | 2 |
| Learning | 1 | 2 |
| Human Capital | 1 | 1 |

Table 15. BoR11.1 'knowledge content' values – Phases 1 & 2

Phase 3. (Developing and disseminating the EWS for routine hospital use)  
There was more change at Phase 3 (see Table 16). The ‘human capital’ and ‘expertise’ attributes both increased slightly, to 2 and 3 respectively, to reflect that new types of technological and commercial expertise were necessary to advance the research and development at this phase, and this led also to a slight reduction in the dominance of doctorate holders over the research process. ‘Learning’ also increased, up to the spectrum’s mid-value of 3. I judged that the practical learning associated with the need to “embed ... new techniques ... and changing behaviours” (McNie et al., 2016, p. 888) throughout an entire hospital was just as significant as the more scientific and codifiable ‘learning’ that resulted from this phase of the research.

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** | **Value (Phase 3)** |
| Expertise | 2 | 2 | 3 |
| Learning | 1 | 2 | 3 |
| Human Capital | 1 | 1 | 2 |

Table 16. BoR11.1 'knowledge content' values – Phases 1-3

#### ‘Intermediary’ values (uncertainty, knowledge exchange, accessibility, boundary management, network participation, flexibility, disciplinary focus, and social capital)

Phase 1. (An auditing system for comparing surgical outcomes across hospitals)  
Table 17 (below) presents the values for the eight ‘intermediary’ activities/attributes. I will start by discussing the ‘disciplinary focus’. As discussed in Chapter 2 when introducing McNie et al.’s (2016) typology, even where academic research exhibits strong ‘Mode 2’ characteristics of transdisciplinarity and a focus on and proximity to contexts of application, disciplinarity still has a role to play, as the expertise, techniques and methodologies drawn upon have largely disciplinary foundations. McNie et al.’s (2016) notion therefore acknowledges that ‘disciplinary focus’ is not a binary, but rather a matter of degree. In this sense, the extent of disciplinarity *mediates* between academia and wider society; academics will be unlikely to disidentify with their disciplinary backgrounds, but they may overcome disciplinary boundaries to a significant extent in terms of their approaches, topics and questions. In the case of BoR11.1, I judged there to be a weak ‘disciplinary focus’ and I coded it as a 4 on the typology’s 1-5 spectrum. This is because the research had little grounding in or interest in advancing a discipline and was rather “organized around problems that are defined by the context of use” (McNie et al., 2016, p. 888), despite the individuals involved drawing on their distinct disciplinary backgrounds (for example medical physics and computing).

This directly influenced the research team’s approach to dealing with ‘uncertainty’. Drawing from McNie et al.’s (2016) description, the researchers involved in BoR11.1 treated “epistemic uncertainty ... as an accepted condition of [the] ... complex ... realities” (p. 888) which they were studying, and it was not their priority to overcome this uncertainty. For example, rather than ask the complex scientific question of *‘what causes deterioration in different types of patients’*, with the implication that a very broad range of data and factors be collected, controlled and measured, the Portsmouth Team had a far more pragmatic ‘what works’ approach to informing clinical practice. This was driven by the epistemically more modest question of *‘how can inpatient data that is already routinely collected by hospitals be used to provide approximate predictions of inpatient deterioration and inform clinical practitioners’ priorities?’* As the approach to ‘uncertainty’ was driven by a pragmatic ‘what works’ approach rather than by a dedication to maximising scientific knowledge, I gave the ‘uncertainty’ attribute a value of 4.

I valued ‘knowledge exchange’, ‘flexibility’ and ‘accessibility’ at 3, the mid-point on the spectrum. This reflects that there was a non-negligible amount of “iterative” communication between users and researchers, and quite significant “collaboration” and “brokering” between different sectors (McNie et al., p. 888). Moreover, the CHMI took steps to facilitating “easy access to [their academic] researchers and knowledge resources”, making itself “more accessible than ‘ivory tower’ research facilities”, and also making it “responsive ... to users’ needs” (ibid. pp. 889, 890). However, I did not give a higher value because these activities/attributes were all somewhat limited, for example there was significant focus on more “one-way” forms of communication which “are consistent with, and understood by, their shared epistemic communities and not with the general public”, emphasising, for example, “peer-review publications” (ibid., p. 888).

For a similar reason, I also gave the low value of 2 for ‘network participation’. Despite the different disciplines and professions of the research team, their interests and expertise coalesced such that they formed a relatively “homogeneous ... epistemic community” (McNie et al., 2016, p. 889). And this situation had implications also for the values assigned to ‘social capital’ and ‘boundary management’, both of which also received a value of 2. Regarding ‘social capital’, although “trust, and relationships [were] necessary to create and share knowledge” amongst the research team, the strongly epistemic nature of the research meant that the main basis of trust, both within the team and between the team and potential users, was “rigorous methods and norms of conducting research”, thereby reducing the importance of and “need for creating or deploying social capital” (ibid., p. 889). And, as such, the demands of ‘boundary management’ and “boundary work” were relatively insignificant, and the “risks of science’s credibility being impugned or of science becoming politicized” were relatively low (ibid., pp. 890-891).

|  |  |
| --- | --- |
| **Attribute/activity** | **Value (Phase 1)** |
| Uncertainty | 4 |
| Knowledge Exchange | 3 |
| Accessibility | 3 |
| Boundary Management | 2 |
| Network Participation | 2 |
| Flexibility | 3 |
| Disciplinary Focus | 4 |
| Social Capital | 2 |

Table 17. BoR11.1 'intermediary' values - Phase 1

Phase 2. (Developing an Early Warning System (EWS) for real-time clinical care)  
I judged the majority of attributes/activities to not require any adjustment at Phase 2 (see Table 18) in comparison with Phase 1, with only two exceptions – ‘accessibility’ and ‘social capital’, which both increased by one, to 4 and 3, respectively. The increased value for ‘accessibility’ reflects the appointment of one NHS scientist as Professor of Health Informatics at CHMI, which increases the accessibility of CHMI to NHS, the main ‘user’ in question. While the value for ‘social capital’ increased because the goal of expanding the application of the researcher’s model to new contexts beyond that demanded by policymakers meant that the researchers had to embark on their own efforts to mobilise wider support. As such, it could be considered that the ‘boundary management’ attribute should also have been increased to reflect this. However, I judged that this was not necessary because although a greater number of individuals would need to be engaged with, they were the same kinds of actors and stakeholders as was previously the case. As I will show, though, Phase 3 did bring greater boundary management challenges.

|  |  |  |
| --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** |
| Uncertainty | 4 | 4 |
| Knowledge Exchange | 3 | 3 |
| Accessibility | 3 | 4 |
| Boundary Management | 2 | 2 |
| Network Participation | 2 | 2 |
| Flexibility | 3 | 3 |
| Disciplinary Focus | 4 | 4 |
| Social Capital | 2 | 3 |

Table 18. BoR11.1 'intermediary' values – Phases 1 & 2

Phase 3. (Developing and disseminating the EWS for routine hospital use)  
As the work associated with Phase 3 was primarily focused on developing existing knowledge and applying it in context, rather than producing new knowledge, I raised the already high value of ‘disciplinary focus’ up from 4 to 5. All other ‘intermediary’ activities/attributes received a value of 4. For ‘accessibility’ and ‘uncertainty’, this meant no change from Phase 2, but for the others, there was need for an increase of either one or two from Phase 3.

These increases reflected the new ‘knowledge exchange’ and ‘boundary management’ challenges associated with their two ambitions. The first of these was to engage with entrepreneurs and further technology experts, with whom some members of the research team started a spin-out company to produce a commercial product which would enable the researchers’ model to be applied digitally within a hospital. Evidence of the increased ‘boundary management’ can be seen in the quite lengthy ‘conflict of interest statements’ in some of the academic articles which I analysed as part of the documentary analysis. The second main ambition was to produce a free version of the model which the researchers hoped would be taken up by the NHS on a large scale. This involved wider forms of ‘network participation’ with a greater range of political actors and sector bodies and putting greater effort into mobilising ‘social capital’ to establish trust. Moreover, it also required greater ‘flexibility’, as was evidenced when one politically powerful group within the sector demanded certain amendments to the model before they would promote its uptake NHS-wide, which the research team were willing to do despite not perceiving it to add analytical value to the model. Table 19 summarises these values.

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** | **Value (Phase 3)** |
| Uncertainty | 4 | 4 | 4 |
| Knowledge Exchange | 3 | 3 | 4 |
| Accessibility | 3 | 4 | 4 |
| Boundary Management | 2 | 2 | 4 |
| Network Participation | 2 | 2 | 4 |
| Flexibility | 3 | 3 | 4 |
| Disciplinary Focus | 4 | 4 | 5 |
| Social Capital | 2 | 3 | 4 |

Table 19. BoR11.1 'intermediary' values – Phases 1-3

#### Summary analysis

As McNie et al. (2016) explain, any given piece or body of research can be “characterized in full by assessing where it lies on the spectrum ... for the entire suite of criteria” (p. 887). Presenting the typology in full “provides a framework to visualize ... the major activities and attributes of research in terms that give equal weight to the consideration of “science values” and “user values”” (ibid., p. 893). Figure 11 presents this visualisation for BoR11.1 (using shading to demarcate the ‘social context’, ‘intermediate’ and ‘knowledge content’).

|  |  |  |
| --- | --- | --- |
| **Classification** | **Attributes/activities** | **Bounded Unbounded**  **1 2 3 4 5** |
| ‘Social context’  values | Goals | 1 2 3 |
| Relevance | 1 2 3 |
| Evaluation | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| ‘Intermediate’ values | Uncertainty | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Accessibility | 1 2 3 |
| Boundary management | 1 2 3 |
| Network | 1 2 3 |
| Flexibility | 1 2 3 |
| Social capital | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| ‘Knowledge content’  values | Expertise | 1 2 3 |
| Learning | 1 2 3 |
| Human capital | 1 2 3 |
| Average | | 1 2 3 |

Figure 11. BoR11.1 typology

This visualisation helps with summarising the BoR for my analytical purposes. Throughout the whole research process, BoR11.1 is strongly engaged in and driven by the ‘social context’ beyond the boundaries of academia, especially in terms of the ultimate goals of the research. By contrast, the ‘knowledge content’ is, for the most part, grounded within academic boundaries. Its progress is dominated by scientifically trained individuals with significant specialist expertise in research and academic publishing. However, by Phase 3, the work is no longer primarily research focused. It is focused rather on developing the underpinning research for both commercial consumption and NHS uptake. By Phase 3, all attributes/activities except for the those related to the ‘knowledge content’, have values of 4 or 5 on the typology’s spectrum, even those ‘intermediate’ attributes/activities which at Phases 1 and 2 were towards the low end of the spectrum (i.e. ‘accessibility’ and ‘boundary management’). As the research progresses, more and more of the research team’s effort is being expended on ‘boundary management’, ‘network participation’ and mobilising ‘social capital’ in order to achieve their ambitions of commercialisation and policy influence, and less is being focused on publishing and fine-tuning the model. The outputs are increasingly ‘user-focused’ (‘use-focused outputs’ being one of the five forms of ‘boundary transaction’), taking the form of patents and other forms of codified knowledge, such as toolkits and technologies. What publishing does take place is not so much a report of new and improved capabilities of the model, but more about showing how the model compares in practice with competitors, while some knowledge goes unpublished due to commercial confidentiality.

All five of the different forms of ‘boundary transaction’ played a part in BoR11.1. The CHMI is an example of a ‘boundary structure’. It engaged in significant ‘outreach’, first as part of building a research ‘collaboration’ team with NHS Trust scientists and medical practitioners, and later with wider policy and sector bodies and technology entrepreneurs, and this collaboration manifested in co-authored journal articles. At least one key ‘boundary-spanner’, appointed to a CHMI professorship from his previous research post within the NHS, was one of the main driving forces underpinning the research team’s initial studies and then later success in leveraging support from external stakeholders. There were also several ‘use-focused outputs’ of the research, most obviously the commercial device which digitised and streamlined application of the research team’s model, but also in the form of journal articles targeting practitioner audiences. Significantly, several of the academics involved took co-ownership over the company which went on to finalise the development, promotion and marketing of the product, so that this company had the effective characteristics of a spin-out (although technically it was not a spin-out as it existed in a different form prior to the academics’ taking a share).

Overall, BoR11.1 is one of only three of the nineteen sampled BoRs to receive an overall value above the mid-value of 3 (BoR11.1’s overall average value is 3.38). Although underpinned by academic research and strongly scientific knowledge content, the focus on developing, marketing and commercialising a product for private profit which characterised much of the BoR meant that its strategies, relationships, dissemination practices – in short, its boundary transactions – were in many ways more akin to those of a small knowledge-intensive business rather than an academic department. I stress that I do not intend to criticise these practices – the researchers were by no means solely motivated by profit and worked hard to ensure that a free, paper-based version of their potentially life-saving product could be rolled out on the NHS, alongside a technological one which would be sold commercially (both abroad and in the UK). And if I was able to continue my analysis of this ongoing body of research further into the future, different results might emerge. But nonetheless, BoR11.1 as it stands provides an interesting case study in how the boundaries of academic knowledge production are being pushed.

### Illustrative case 2. ‘Moderately bounded’ research (BoR5)

BoR5 is titled ‘Sea Mammal Research & Impact’. It is based at the Sea Mammal Research Unit (SMRU), based in the School of Biology and St Andrews University. SMRU started life in as a non-academic public research unit within the Natural Environment Research Council (NERC), created to fulfil NERC’s obligation to advise the UK Government on seal management according to NERC’s Royal Charter and the Conservation of Seals Act 1970. In 1996, SMRU was moved to St Andrews School of Biology, with NERC continuing to provide the funding necessary for SMRU to complete its statutory work. The overall discipline which best describes SMRU’s research is marine ecology, with particular focus on the interdisciplinary subfield of marine mammalogy. This implies that while SMRU research makes some fundamental advances in knowledge, the ‘use’ of knowledge is a major driver of the research.

In terms of the institutional and epistemic context, BoR5 (from REF UoA5, Biology) was sampled as a Basic life science in a ‘more prestigious’ departmental context. Table 20 presents BoR5’s typology values by the three ‘research dimensions’ (‘social context’, ‘intermediary’ and ‘knowledge content’) and, for comparison, shows how these compare with other research sharing its contextual characteristics and with the overall sample average. It shows that BoR5 has relatively high knowledge content and intermediary values, but low social context values.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Social Context | Intermediary | Knowledge Content |
| **BoR5** *(basic, life, ‘more prestigious’)* | **2.83** | **2.63** | **1.67** |
| ‘Basic’ average | 3.24 | 2.37 | 1.52 |
| ‘Life’ average | 3.17 | 2.42 | 1.72 |
| ‘More prestigious’ average | 3.4 | 2.46 | 1.54 |
| **Sample average** | **3.54** | **2.43** | **1.58** |

Table 20. BoR5 typology values by 'research dimension' (with comparator values)

As before, I will start by discussing the ‘social context’ in detail.

#### ‘Social context values’ (goals, relevance, evaluation and outputs & outcomes)

Phase 1. (Co-advancement of science and technology)  
Sea mammals, such as seals, are top predators in marine ecosystems. As such, they often are in competition with human fisheries for fish and this has prompted calls from fisheries for governments to control seal populations. Sustainable control requires detailed knowledge about both population distribution and seal behaviour, particularly behaviour related to foraging habits. Therefore, driven by the desire to inform economic, environmental and political debate around seal population management, research at SMRU from the 1990s focused on improving instrumentation for remotely tracking and collecting data about seals in their natural habitats.

I gave the ‘goals’ attribute a value of 3. This is because the immediate goals were strongly scientific, focused on advancing knowledge within the interdisciplinary sub-field of mammalogy (which brings together elements of marine zoology and ecology), but the longer-term goals were to inform and influence policy about balancing economic needs and conservation. For similar reasons I gave the same value of 3 to the ‘relevance’ attribute. Although the ultimate aim of the research was to produce information of relevance to the social context of political debate, economic aquaculture and seal conservation, the knowledge produced also had broader scientific relevance (a point which directly informs Phase 3, as I will explain below).

I gave lower values for ‘outputs & outcomes’ and ‘evaluation’ – a 2 for both. The outputs are predominantly what McNie et al. (2016) would term “narrow”, taking the form of “peer-reviewed publications, ... patents, ... [and] new methods and processes”, while the “primary outcome is new knowledge and the improved understanding of phenomena” (p. 890). These are all relatively science-focused characteristics. As such, the ‘evaluation’ and success criteria at Phase 1 were mainly defined in terms of their success in these “narrow” outputs (ibid., p. 890). Table 21 summarises these values.

|  |  |
| --- | --- |
| **Attribute/activity** | **Value (Phase 1)** |
| Goals | 3 |
| Relevance | 3 |
| Evaluation | 2 |
| Outputs | 2 |

Table 21. BoR5 'social context' values - Phase 1

Phase 2. (Methodological innovations)  
The data obtained by the instrumentation developed at Phase 1 was extensive and extremely complex. This meant that SMRU then needed methodological advances to cope with this new data. This mainly took the form of statistical research and innovation, with the aims of estimating the error inherent in existing methods and in maximising the analytical potential of newly acquired data. For example, SMRU’s statistical research involved using their new instrumentation and techniques to calculate estimates of the errors inherent in the data from satellite systems used by different research groups around the world. They also proposed and tested novel statistical methods.

Regarding the typology (see Table 22), I judged all values to be the same for Phase 2 as they were at Phase 1 – 3 for ‘goals’ and ‘relevance’, and 2 for ‘outputs & outcomes’ and ‘evaluation’. This is because, even though the content of Phase 2 had moved on from and built upon that from Phase 1, its relation to the ‘social context’ was, according to my interpretation, the same.

|  |  |  |
| --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** |
| Goals | 3 | 3 |
| Relevance | 3 | 3 |
| Evaluation | 2 | 2 |
| Outputs | 2 | 2 |

Table 22. BoR5 'social context' values – Phases 1 & 2

Phase 3. (Dissemination and revenue-generation)  
SMRU researchers believed that their technological, methodological and theoretical advances had potentially broader applications in conservation management, as well as for those sectors potentially affected by conservation regulations, such as the energy and naval industries, whose operations often bring them into contact with marine life. Phase 3 centres around SMRU’s efforts to explore, develop and explain their technologies’ potential broader applicability.

On the typology (see Table 23), all four of the ‘social context’ values were increased by one – 4 for ‘goals’ and ‘relevance’, and 3 for ‘evaluation’ and ‘outputs & outcomes’. This judgement was based on the following factors. I judged the goals of Phase 3 to be more “outcomes-oriented” (McNie et al., 2016, p. 888) than previously. This was evidenced by the outputs of Phase 3, which were focused not so much on producing new fundamental scientific knowledge, but rather on highlighting the relevance of their earlier work to conservation management. Moreover, although these outputs were still predominantly taking typical forms of publications, these publications were more focused and targeted at specific audiences. Furthermore, other kinds of outputs and outcomes did emerge, including workshops with practitioners on how to apply SMRU’s methods in different contexts. There were also commercial outcomes, with SMRU selling their technologies via SMRU’s spin-out company, SMRU Instrumentation. Lastly, the criteria of success of the work at Phase 3 was the interest in and uptake of these methods and technologies by others.

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** | **Value (Phase 3)** |
| Goals | 3 | 3 | 4 |
| Relevance | 3 | 3 | 4 |
| Evaluation | 2 | 2 | 3 |
| Outputs | 2 | 2 | 3 |

Table 23. BoR5 'social context' values – Phases 1-3

#### ‘Knowledge content’ values (expertise, learning, human capital)

Phases 1, 2 and 3 combined  
I have combined discussion of Phases 1, 2 and 3 because none of the ‘knowledge content’ values changed across the three phases (see Table 24). I gave ‘expertise’ a value of 1 at all three phases. This reflects that, in this contested political space, the “credibility to produce knowledge” that will feed into policy was based on appearing objective and neutral, and this meant displaying the “specific training, norms and behaviours … consistent with those in academia” and “being considered experts in their field and … by society” (McNie et al., 2016, p. 887). All those involved in the conduct of research were academic scientists based at SMRU and having relevant doctoral qualifications. However, I chose to give a slightly higher value of 2 for the ‘human capital’ attribute. This is because, despite the high academic qualifications of all those involved in producing and defining the knowledge content associated with this BoR, it was also important that at least some of these researchers exhibited other “kinds of skills and training”, for example “soft skills” associated with “communication, translation and mediation” (ibid., p. 890). The political nature of the social context, which meant that the credibility to produce knowledge had to be grounded in scientific expertise, is precisely why it was also important these scientific experts had these ‘soft’ skills in addition to their scientific training.

I gave a value of 2 for ‘learning’ at all three phases. Although, as I will show below, the dissemination of the research (‘knowledge exchange’) involved slightly more significant boundary-crossing interactions, the actual knowledge content of what was learned was, at each phase, primarily theoretical, “focused on understanding theories” (ibid., p. 888) in the sub-discipline of mammalogy. As one of my interview participants explained, SMRU are keen to ensure that they maintain their image as credible and objective informants, and therefore deliberately avoided involvement in research or argumentation about “developing new policies” (ibid., p. 888), that is they do not attempt to improve or influence other aspects of the policymaking process other than the evidence base on which policy is formulated.

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** | **Value (Phase 3)** |
| Expertise | 1 | 1 | 1 |
| Learning | 2 | 2 | 2 |
| Human Capital | 2 | 2 | 2 |

Table 24. BoR5 'social context' values - Phases 1-3

#### ‘Intermediary’ values (uncertainty, knowledge exchange, accessibility, boundary management, network participation, flexibility, disciplinary focus, and social capital)

Phase 1. (Co-advancement of science and technology)  
I judged all the ‘intermediate’ values at Phase 1 to be either a 2 (‘uncertainty’, ‘boundary management’, ‘flexibility’, ‘social capital’) or a 3 (‘knowledge exchange’, ‘accessibility’, ‘network participation’ and ‘disciplinary focus’) on the typology’s spectrum (summarised in Table 25).

Starting with ‘disciplinary focus’, I gave this attribute a value of 3 because, on the one hand, the SMRU brings together a “transdisciplinary” (McNie et al., 2016, p. 888) group of experts, including ecologists, zoologists, statisticians and engineers, whose integration is “organised around problems” (ibid., p. 888) generated beyond academia. That is, it is oriented towards informing the real-life context of marine life and its interaction with human society, and the political dynamics this throws up vis-à-vis tensions between economic activity and ecological conservation. On the other hand, this integration of scientific expertise and the approach and content of the research is “largely guided by ... disciplines” (ibid., p. 887), specifically the sub-discipline of mammalogy.

For similar reasons, I also gave the ‘accessibility’ attribute a value of 3. On the one hand, the SMRU’s remit and focus, including its history as a body to produce statutory scientific information to the UK government, gives it some “proximity” (ibid., p. 889) to the relevant social context. But there are limits to this accessibility, as I found from interviewing a professor at SMRU. For example, organisationally, since moving from NERC to St Andrews University, SMRU has been focused on establishing its internal legitimacy as part of the School of Biology, as they felt the need to overcome their identity as a governmental research unit. Transitioning into a valued contributor to the broader discipline of biology has meant the need to somewhat limit their ‘accessibility’ to external actors, and to focus on more traditional departmental activities, such as building a base of undergraduate, postgraduate and research students, and publishing in disciplinary journals. Moreover, my interview revealed that SMRU are discerning when it comes to which kinds of actors they will conduct research for, as they generally will refuse to conduct research if they believe the sponsor has a particular agenda which is likely to influence how they use that research.

These characteristics influence the ‘flexibility’ attribute even more strongly, which I valued at 2. Although there is some ‘flexibility’ in the sense that SMRU are willing and able “to respond to emerging opportunities … and users’ needs … in strategic ways”, they are relatively “inflexible” in terms of their “rules of operations” which centre around “rather predictable forms of research conduct and applications” (McNie et al., 2016, p. 890).

Regarding SMRU’s approach to dealing with ‘uncertainty’, I judged this to be a value of 2. Guided by their preference for producing an objective evidence base for policymakers to draw from, the SMRU’s approach to uncertainty tended towards the more scientific approach of ‘reducing’ “epistemic uncertainty” and “ensuring the highest degree of accuracy and precision” (ibid., p. 888). One of the implications for this is that the knowledge produced is relatively complex, and SMRU researchers must engage in quite significant and broad forms of ‘knowledge exchange’ and ‘network participation’ in order to ensure the relevant information is picked up and appropriately interpreted by stakeholders and policymakers. It is for this reason I give the slightly higher value of 3 to ‘knowledge exchange’ and ‘network participation’.

SMRU’s position as objective and disinterested experts influences their experience in these knowledge exchange and dissemination networks. Despite the political and contested nature of the issues on which SMRU are informing, this image of objective expert lowers the “risk of politicization” (ibid., p. 890) of their work, meaning the need for engaging in ‘boundary management’ is reduced – SMRU may engage in various cross-boundary networks and activities, but they do so with distinctly academic identities, and their lack of interest in policy outcomes means that these identities go relatively unchallenged. I therefore gave the ‘boundary management’ activity a value of 2. For similar reasons, I also gave the ‘social capital’ attribute the same value of 2. Since trust in SMRU is predominantly grounded in their scientific “methods and norms”, there is relatively “negligible” need to “develop” and “deploy” social capital (ibid., p. 889).

|  |  |
| --- | --- |
| **Attribute/activity** | **Value (Phase 1)** |
| Uncertainty | 2 |
| Knowledge Exchange | 3 |
| Accessibility | 3 |
| Boundary Management | 2 |
| Network Participation | 3 |
| Flexibility | 2 |
| Disciplinary Focus | 3 |
| Social Capital | 2 |

Table 25. BoR5 ‘intermediary’ values – Phase 1

Phase 2. (Methodological innovations)  
As summarised in Table 26, three of the ‘intermediate’ values changed in Phase 2 in relation to Phase 1 – ‘disciplinary focus’, ‘social capital’ and ‘uncertainty’. Regarding ‘disciplinary focus’, I judged that this should receive a lower (more academically ‘bounded’) value at Phase 2 than at Phase 1 because the methodological, statistical research which characterises Phase 2 meant that this work was couched more in terms of ecological theory. And, in line with this increased disciplinary and methodological focus, the issue of ‘social capital’ became even less of an issue than was previously the case, and I coded this as a 1.

By contrast, I judged ‘uncertainty’ to be a 3, an increased from Phase 1. As McNie et al. (2016) explain, in some cases, “[m]ore information does not necessarily reduce uncertainty and can in fact increase it” (p. 888). This is part of the challenge that SMRU faced after technological advances gave them access to broader and deeper (literally) data about seal behaviour. Several of the journal articles associated with BoR5 emphasise the complexity of studying seals due to their being part of an ‘open’ and unpredictable ecological system. The statistical research conducted at Phase 2 was about attempting to “manage” (ibid., p. 888) the uncertainty inherent in the data; that is, to make the data more manageable for reporting and advising purposes.

|  |  |  |
| --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** |
| Uncertainty | 2 | 3 |
| Knowledge Exchange | 3 | 3 |
| Accessibility | 3 | 3 |
| Boundary Management | 2 | 2 |
| Network Participation | 3 | 3 |
| Flexibility | 2 | 2 |
| Disciplinary Focus | 3 | 2 |
| Social Capital | 2 | 1 |

Table 26. BoR5 ‘intermediary’ values – Phases 1 & 2

Phase 3. (Disseminating technologies and techniques, generating revenue)

As Table 27 shows, I increased four of the attribute/activity values at Phase 3 – ‘boundary management’, ‘network participation’, ‘disciplinary focus’ and ‘social capital’.

SMRU broadened both their academic and non-academic networks, including more disparate scientific disciplines, conservation practitioners, and researchers from non-academic public research institutes (both at home and abroad) in order to disseminate their technologies and methods. This also stretched as far as commercialisation, leading to networks engaging private sector industry. I therefore increased my valuation of ‘network participation’ on the typology’s spectrum from 3 to 4.

These developments also influenced my valuation of other activities/attributes. This more interventionist approach, where SMRU more actively aimed to disseminate and commercialise their methods had implications for ‘boundary management’ and the need for deploying ‘social capital’, both of which I increased up to a value of 3.

In the case of ‘disciplinary focus’, I originally valued this as a 3 at Phase 1, but reduced this to a 2 at Phase 2, reflecting the greater disciplinary focus associated with SMRU’s methodological innovations and statistical research. The work at Phase 3 goes back to a similar level of disciplinary focus as at Phase 1, and I accordingly have valued this attribute as a 3 at this phase.

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** | **Value (Phase 3)** |
| Uncertainty | 2 | 3 | 3 |
| Knowledge Exchange | 3 | 3 | 3 |
| Accessibility | 3 | 3 | 3 |
| Boundary Management | 2 | 2 | 3 |
| Network Participation | 3 | 3 | 4 |
| Flexibility | 2 | 2 | 2 |
| Disciplinary Focus | 3 | 2 | 3 |
| Social Capital | 2 | 1 | 3 |

Table 27. BoR5 ‘intermediary’ values – Phases 1-3

#### Summary analysis

Figure 12 presents BoR5’s typology in full. It highlights that BoR5 is far less directly and intensively engaged in the social context than was the case with BoR11.1, discussed above (see Figure 11). Although its ultimate goals are to inform decisions beyond academic boundaries, its immediate outputs are predominantly scientific. This is also reflected in the low ‘knowledge content’ values, albeit that the boundary-crossing networks that SMRU engage in has forced them to learn to combine their ‘hard’ scientific skills with some ‘softer’ skills, as reflected in the values for ‘network participation’ and ‘human capital’. However, even when engaging with wider networks, the strong emphasis on scientific expertise colours the image and identities that SMRU carry. This explains why, for the most part, the need for expending effort on ‘boundary management’ and mobilising ‘social capital’ is relatively low; in the contexts of the boundary-crossing networks that SMRU engage in, it is their academic/scientific capital (Langa, 2011) that is important and, for the most part, it is sufficient for their legitimacy to contribute to debates.

|  |  |  |
| --- | --- | --- |
| **Classification** | **Attributes/activities** | **Science-oriented User-oriented**  **1 2 3 4 5** |
| ‘Social context’  Values | Goals | 1 2 3 |
| Relevance | 1 2 3 |
| Evaluation | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| ‘Intermediate’ values | Uncertainty | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Accessibility | 1 2 3 |
| Boundary management | 1 2 3 |
| Network | 1 2 3 |
| Flexibility | 1 2 3 |
| Social capital | 2 1 3 |
| Disciplinary focus | 2 1 3 |
| ‘Knowledge content’  values | Expertise | 1 2 3 |
| Learning | 1 2 3 |
| Human capital | 1 2 3 |

Figure 12. BoR5 typology

Like CHMI (from BoR11.1, discussed above), SMRU is a boundary structure, what I term a ‘transdisciplinary’ boundary structure, in that it brings together biologists, physicists, statisticians and technologists whose expertise coalesces around the sub-field of marine mammalogy. Also resembling CHMI, SMRU has its own off-shoot boundary structures in the form of SMRU Consulting and SMRU Instrumentation, spin-outs which aim to generate revenue based on SMRU technology and expertise. More than just a boundary structure, SMRU can be conceptualised as a ‘boundary-*spanning* structure’, since for two decades it existed as a non-academic public research institute conducting scientific research directly for policy and regulatory purposes. It now continues these functions, but it does so through its outreach, networking and use-oriented outputs. These take the form of technologies, workshops, seminars, advice, consultancy, as well as journal articles targeting broad audiences beyond SMRU’s own specialism. Unlike the researchers from CHMI (BoR11.1) though, SMRU researchers were careful to uphold a strict, ‘bounded’ notion of academic identity in their transactions. For example, the funds raised from the spin-out did not go to shareholders, but only to pay for salaries of its staff and for the development of technologies used to enable SMRU’s basic research. Moreover, its outreach with those involved in making policy or affected by policy did not involve any attempts to influence a specific policy, but only aimed to inform (in contrast with CHMI researchers who worked for uptake of their specific benchmarking model, potentially in competition with others).

In sum, my analysis sees the boundary transactions associated BoR5’s research as reinforcing the distinctive value, legitimacy and identity of academia and thereby functioning towards the reproduction of academic boundaries. This is not due to some unique approach developed by SMRU researchers, but by (i) working within a particular kind of (use-inspired basic) disciplinary context such that the contribution to ‘impactful’ knowledge was inseparable from their contribution to ‘basic’ scientific knowledge, and (ii) placing great reliance on their academic and scientific capital as the basis for legitimacy in informing policy debates and decision-making.

### Illustrative case 3. ‘Bounded’ research (BoR4.2)

The third and final illustrative case is that of BoR4.2, ‘Informing MDMA Policy’, based at the University of East London’s (UEL), School of Psychology. Specifically, the researchers involved belong to the Drugs and Addictive Behaviours Research Group (DABRG), whose members also established the wider Substance Use and Misuse (SUM) network, through which its research is disseminated amongst policy actors, other user groups, and also other scientific specialists from different disciplines. The context of this research is that the School of Psychology represents a ‘less prestigious’ institutional context, and the research is ‘Basic/Applied’ and belongs to the ‘life’ branch of sciences. As Table 28 shows, BoR4.2 has very low values across all dimensions.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Social Context | Intermediary | Knowledge Content |
| **BoR4.2** *(basic/applied, life, ‘less prestigious’)* | **2.58** | **1.58** | **1.11** |
| ‘Basic/Applied’ average | 3.06 | 2.3 | 1.78 |
| ‘Life’ average | 3.17 | 2.42 | 1.72 |
| ‘Less prestigious’ average | 3.49 | 2.63 | 1.78 |
| **Sample average** | **3.54** | **2.43** | **1.58** |

Table 28. BoR4.2 typology values by 'research dimension' (with comparator values)

As with the other two illustrations, I will start by describing my coding of the ‘social context’ attributes.

#### ‘Social context’ values (goals, relevance, evaluation, outputs & outcomes)

Phase 1. Contributing to psychopharmacological understanding of MDMA (ecstasy)  
DABRG’s research is best described as belonging to the inherently interdisciplinary and use-inspired field of *psychopharmacology*, which is concerned with the effect of both licit and illicit pharmaceuticals on cognitive functioning. Within this disciplinary context, the main guiding principle for their research agenda has been delineating the extent of long-term health impacts of exposure to certain drugs in order to inform the health profession, drug users, and government policy.

In this case, the drug in question was MDMA, popularly known as ‘ecstasy’. In the 1990s, there were reports that MDMA could have certain benefits to the user, and some who believed that these could potentially outweigh the known risks. DABRG were originally therefore interested in two main questions: *Do the negative effects of MDMA outweigh apparent benefits? What psychopharmacological mechanisms underpin observed effects?*

DABRG conducted systematic reviews and novel empirical studies. Based on this work, DABRG were able to provide in greater detail than previous studies the significant negative effects of MDMA on cognitive functioning and mood in both the short and long term. Moreover, they showed that the strength of these effects correlate with both frequency and quantity of MDMA use. Additionally, in terms of the underpinning scientific mechanisms, they provided strong evidence in support of their hypothesis that these effects are the direct result of damage to neurons which release a chemical (serotonin) that is associated both with the feeling of elation brought on by ecstasy pills and with cognitive functioning (e.g. memory).

On the typology (summarised in Table 29), I judged both the ‘goals’ and ‘relevance’ of this research to have a value of 3, since they were, in my view, in equal part scientific *and* oriented towards and of relevance to contexts of use; that is, this research fits the definition of what has been termed ‘use-inspired basic’ research (Hughes et al., 2016; Stokes, 1997). However, I gave lower values to ‘outputs and outcomes’ (1) and ‘evaluation’ (2). The outputs and outcomes were, at this stage, strongly scientific, taking the form of specialist academic publications targeted at DABRG’s immediate scientific community. As such, although the researchers evaluated their own work partly in terms of its potential relevance, at this phase, the main site evaluation was that of scientific opinion by peer review.

|  |  |
| --- | --- |
| **Attribute/activity** | **Value** |
| Goals | 3 |
| Relevance | 3 |
| Evaluation | 2 |
| Outputs | 1 |

Table 29. BoR4.2 'social context' values - Phase 1

Phase 2. Contributing to practical debates around MDMA  
Having advanced the scientific understanding of the causes and effects of MDMA, DABRG follow-up work focused on ascertaining the extent, nature and mediating factors (i.e. frequency, length and conditions of MDMA use) of negative effects in users. This research advanced understanding of the real-life contexts of MDMA use and its impacts. The strengthened body of evidence produced by this research influenced the UK Government’s decision to maintain MDMA’s status as a Class A drug, which went against official recommendation by the UK Advisory Council on the Misuse of Drugs that it be reduced to Class B.

I judged that the ‘goals’ and ‘relevance’ of the research was equivalent to that in Phase 1 (both values of 3). However, the ‘evaluation’ and ‘outputs & outcomes’ of this phase of research did involve slightly more engagement in the ‘social’ context (i.e. in the form of advising and aiming to shape government policy), and I increased both values by one, that is, a 3 for ‘evaluation’ and a 2 for ‘outputs & outcomes’. These values are summarised in Table 30.

|  |  |  |
| --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** |
| Goals | 3 | 3 |
| Relevance | 3 | 3 |
| Evaluation | 2 | 3 |
| Outputs & outcomes | 1 | 2 |

Table 30. BoR4.2 'social context' values – Phases 1 & 2

Phase 3. Scientific advances prompt new demand for knowledge  
DABRG’s success in evidencing the long-term cognitive damage of MDMA in adult users prompted a new concern about the effects that MDMA use by pregnant women may have on children. DABRG collaborated on a large-scale, longitudinal study funded by the United States Government’s National Institute for Drug Abuse (NIDA) into MDMA use of pregnant women and the cognitive effects on children at various intervals after birth.

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** | **Value (Phase 3)** |
| Goals | 3 | 3 | 3 |
| Relevance | 3 | 3 | 3 |
| Evaluation | 2 | 3 | 3 |
| Outputs & outcomes | 1 | 2 | 2 |

Table 31. BoR4.2 'social context' values – Phases 1-3

#### ‘Knowledge content’ values (expertise, learning, human capital)

Phase 1 and Phase 2 combined

As there is no change in any of the three ‘knowledge content’ values (see Table 32) between Phase 1 and Phase 2 for BoR4.2, I combine discussion of the two phases here.

In Phases 1 and 2, all ‘knowledge content’ values exhibited strongly scientific characteristics, and all received the lowest value of 1. “Epistemic” expertise and the highest levels of academically bestowed “human capital” were the criteria for engagement in the research, with all involved having PhDs and academic research posts (McNie et al., 2016, pp. 887, 890). What was learned from the research was grounded in “understanding [psychopharmacological] theories and … explicit knowledge that can be easily transferred between people through documents” (ibid., p. 888), i.e., academic journal articles.

|  |  |  |
| --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** |
| Expertise | 1 | 1 |
| Learning | 1 | 1 |
| Human Capital | 1 | 1 |

Table 32. BoR4.2 ‘knowledge content’ values – Phases 1 & 2

Phase 3. Scientific advances prompt new demand for knowledge

There was only a very slight change in my valuation of the ‘knowledge content’ associated with Phase 3 (see Table 33) in relation to Phases 1 and 2. This relates to the attribute of ‘human capital’, which I increased from a value of 1 to 2 – values for ‘expertise’ and ‘learning’ remained the same.

The small increase in the value for ‘human capital’ reflects that, at this phase, DABRG scientists had to develop and exert ‘softer’ skills as well as their ‘hard’ skills (McNie et al., 2016), as they began to disseminate and discussed their research widely and in the public arena. This involved advice, talks and interviews internationally via the media, governmental agencies, pregnancy and parenting websites, and medical professionals.

|  |  |  |
| --- | --- | --- |
| **Attribute/activity** | **Value (Phases 1 & 2)** | **Value (Phase 3)** |
| Expertise | 1 | 1 |
| Learning | 1 | 1 |
| Human Capital | 1 | 2 |

Table 33. BoR4.2 ‘knowledge content’ values – Phases 1-3

#### ‘Intermediary’ values (uncertainty, knowledge exchange, accessibility, boundary management, network participation, flexibility, disciplinary focus, and social capital)

Phase 1. Contributing to psychopharmacological understanding of MDMA (ecstasy)  
At Phase 1, I judged all ‘intermediary’ values to be a 1 on the typology’s spectrum, with only one exception, that is, the ‘uncertainty’ attribute, which I gave a value of 2 (see Table 34).

‘Intermediary’ attributes/activities are those aspects of research which typically can serve as a bridge between, or ‘mediate’ between the epistemic context of the knowledge content and the social context of application. At Phase 1 in BoR4.2, I judged that these functions necessitated negligible interaction or cognizance of the social world beyond that of academic boundaries. For example, the ‘knowledge exchange’ that took place was effectively only the “one-way” (McNie et al., 2016, p. 888) communication of science to society through journal articles, which, in this case, was targeted at a specialist audience. There was therefore little if any need for mobilising ‘social capital’, ‘boundary management’, or being ‘flexible’ to evolving external issues.

This does not necessarily mean that DABRG were overall not cognizant of or disinterested in wider issues and the implications of their research for policy, health practitioners and MDMA users. It simply means that their interest manifested in other ways. This is related to the nature of DABRG’s interdisciplinary sub-field of psychopharmacology. As noted, it is an inherently ‘use-inspired’ field of research. In this case, the immediate goals of the research are to advance the discipline, and this involves traditional (i.e. ‘Mode 1’) patterns of knowledge production practices, reflected in the very low values I have given BoR4.2 on the ‘knowledge content’ and ‘intermediary’ values. But because the underpinning goals of this discipline are oriented towards use, research within this discipline can have potential use-value and use-orientation even though the process of research may have little direct interaction with users or stakeholders.

As noted, the only slight exception at Phase 1 was the attribute of ‘uncertainty’. Although the approach to dealing with uncertainty was primarily scientific, aiming to advance fundamental understanding of psychopharmacological phenomena, there was a limit to this. That is, although DABRG are committed to asking the underpinning scientific question of *why* certain substances cause certain effects, this was only ever one part of their goal, and is always mediated by the main goal of understanding and informing decisions about social and personal issues, such as: why certain individuals take these drugs; how the psychopharmacological effects impact on their experienced cognition and their lives more generally; how positively or negatively society should perceive a certain drug; and how much policy attention should therefore be afforded to a given drug. Given these broader goals, DABRG did not always aim solely to “reduce uncertainty”, but occasionally had to trade-off “accuracy and precision” for practical value (McNie et al., 2016, p. 888).

|  |  |
| --- | --- |
| **Attribute/activity** | **Value (Phase 1)** |
| Uncertainty | 2 |
| Knowledge Exchange | 1 |
| Accessibility | 1 |
| Boundary Management | 1 |
| Network Participation | 1 |
| Flexibility | 1 |
| Disciplinary Focus | 1 |
| Social Capital | 1 |

Table 34. BoR4.2 ‘intermediary’ values – Phase 1

Phase 2. Contributing to practical debates around MDMA

As Table 35 shows, four of the ‘intermediary’ values changed in Phase 2 in relation to Phase 1 – ‘knowledge exchange’, ‘boundary management’, ‘network participation’ and ‘social capital’.

In all four of these attributes/activities, their values increased only slightly, up to a value of 2 (all having been coded as 1 at Phase 1). These increases reflect the fact that Phase 2 saw DABRG researchers engage in broader ‘network participation’ and more personal forms of ‘knowledge exchange’ with policymakers, and this involved some level of ‘boundary management’ and deployment of ‘social capital’, particularly as the advice they gave to policymakers put them into direct debate with the UK’s official policy advisory board on the issue of MDMA’s legal classification. However, the extent of this was limited, since their engagement in this process was underpinned by scientific expertise and “credibility” (McNie et al., 2016, p. 888) to comment on MDMA policy. As such, I judged that these ‘intermediary’ values required only a slight increase from Phase 1.

|  |  |  |
| --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** |
| Uncertainty | 2 | 2 |
| Knowledge Exchange | 1 | 2 |
| Accessibility | 1 | 1 |
| Boundary Management | 1 | 2 |
| Network Participation | 1 | 2 |
| Flexibility | 1 | 1 |
| Disciplinary Focus | 1 | 1 |
| Social Capital | 1 | 2 |

Table 35. BoR4.2 ‘intermediary’ values – Phases 1 & 2

Phase 3. Scientific advances prompt new demand for knowledge

Three ‘intermediary’ values changed at Phase 3 – ‘knowledge exchange’, ‘flexibility’ and ‘disciplinary focus’ (see Table 36). I will explain these changes below.

The increase of ‘knowledge exchange’ up to a value of 3 reflects that knowledge exchange and dissemination at Phase 3 saw DABRG researchers engage more with the broader lay-public. Underpinning this was DABRG’s researchers’ role in revealing the potential impact on unborn children of MDMA intake by pregnant mothers. This finding prompted a more active and almost interventionist approach on the part of at least some of the DABRG team, as they actively engaged in attempting to spread their results to a global audience in order to protect future mothers and children.

I increased the values of ‘disciplinary focus’ and ‘flexibility’ because the research which led to the above finding saw DABRG collaborate with other researchers beyond their own specialism to answer research questions which were only partly psychopharmacological in nature, and this shift reflected the ‘flexibility’ of DABRG to adapt their approach when an opportunity to arose to conduct research with larger potential social impact than their previous work had done.

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute/activity** | **Value (Phase 1)** | **Value (Phase 2)** | **Value (Phase 3)** |
| Uncertainty | 2 | 2 | 2 |
| Knowledge Exchange | 1 | 2 | 3 |
| Accessibility | 1 | 1 | 1 |
| Boundary Management | 1 | 2 | 2 |
| Network Participation | 1 | 2 | 2 |
| Flexibility | 1 | 1 | 2 |
| Disciplinary Focus | 1 | 1 | 2 |
| Social Capital | 1 | 2 | 2 |

Table 36. BoR4.2 ‘intermediary’ values – Phases 1-3

#### Summary analysis

BoR4.2 primarily exhibits three of the five main forms of boundary transaction: ‘boundary structures’, ‘use-focused outputs’ and ‘outreach’. DABRG, partly through its boundary structure, the Substance Use and Misuse network (SUM), ‘reaches out’ to policymakers and health practitioners. They also reach out to the public via various media platforms with specific research findings. One of the relevant concepts that DABRG contribute to and disseminate is that of ‘serotonin syndrome’, which functions as what I call a ‘bridging concept’ (a form of ‘use-focused output’). A ‘bridging concept’ is a concept which condenses underpinning scientific research and theory into a more readily understandable concept so as to be suitable for consideration and application by non-specialist users and stakeholders. The bridging concept in this case, ‘serotonin syndrome’, refers to negative effects associated with given levels of chemical build-up of serotonin caused by using MDMA. DABRG’s research using this concept has fed into MDMA policy as described above, and the concept itself is referred to on NHS webpages aimed at the general public[[20]](#footnote-20), so that in this case the concept has also ‘bridged’ to the public domain.

Taking a broader perspective, Figure 13 shows that BoR4.2 displays no values which exceed the typology’s mid-point on the spectrum of 3. The full range of activities and attributes associated with BoR4.2 is strongly ‘bounded’, and only occasionally involves significant interaction across academic boundaries. Nonetheless, because of the inherently use-inspired nature of the underpinning research, DABRG were able to achieve significant ‘impact’ with only relatively modest amounts of boundary-crossing interaction and transaction.

|  |  |  |
| --- | --- | --- |
| **Classification** | **Attributes/activities** | **Science-oriented User-oriented**  **1 2 3 4 5** |
| ‘Social context’  Values | Goals | 1 2 3 |
| Relevance | 1 2 3 |
| Evaluation | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| ‘Intermediary’ values | Uncertainty | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Accessibility | 1 2 3 |
| Boundary management | 1 2 3 |
| Network | 1 2 3 |
| Flexibility | 1 2 3 |
| Social capital | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| ‘Knowledge content’  values | Expertise | 1 2 3 |
| Learning | 1 2 3 |
| Human capital | 1 2 3 |

Figure 13. BoR4.2 typology

What BoR4.2 highlights, then, is that research which is strongly science-oriented and operates primarily within the confines of academic boundaries can, at least under certain conditions, be conducive to highly effective boundary-crossing transactions, which go on to have ‘significant impact’ (at least as judged by the REF). For example, in the context of a use-inspired discipline such as psychopharmacology, it may be that low rather than high values on the ‘disciplinary focus’ attribute of the typology – as exhibited by BoR4.2 – is an important feature of research likely to achieve impact. This is a similar analysis to that presented for BoR5. But the main difference with BoR5 was that the research had more immediate and actively contested relevance to certain sectors of the economy, and therefore the expert advice and scientific output of SMRU (responsible for BoR5) was in greater demand. By contrast, although there were clear potential users of the knowledge produced by DABRG researchers (responsible for BoR4.2), their incentives for demanding such knowledge were not so great – these potential users would be likely to respond and use DABRG’s research, but would not have been likely to actively demand and commission it, nor were the decisions based on DABRG’s research likely to be so heavily scrutinised. What BoR4.2 highlights, particularly in comparison with BoR5, is that different bodies of research may have similar research approaches and orientations (i.e. producing ‘use-inspired basic’ knowledge) but not necessarily engage in the same kind or extent of boundary transactions, as the form of boundary transactions can also be shaped by the external context. Although part of the aim of my research is to explore the influence that the ‘non-academic’ has on academia, it is beyond the scope of my research to explore in detail why some external conditions demand knowledge in different ways and at different levels of intensity to others. Having said that, this result prompts me, in later to sections, to try to take into account the kinds of ‘user’ group that my BoRs engage with and whether different types of user are associated with different characteristics of research or boundary transaction.

## Towards an explanatory analysis

This section is the culmination of the current chapter, which has presented analyses and findings from the data. This section takes the analysis further than previous sections in that it aims to: (i) contextualise the forms and functioning of boundary transactions in the sampled bodies of research (BoRs); (ii) analyse these boundary transactions according to the contextual dimensions of interest – departmental status, branch of science and orientation of discipline; (iii) highlight the variations *within* each of these three contextual dimensions, and (iv) explore these variations using all available documentary and interview data in order to explore the reasons for observed variations.

Table 37, below, condenses the observed variations within each of the three contextual dimensions, and I will refer back to it throughout this section, as the data within it raises issues to be addressed and explored in depth. For example, Table 37 shows that ‘elite’ institutional contexts stand out in terms of having the lowest ‘intermediary’ (2.15) and ‘knowledge content’ values (1.45) of all nine categories. This suggests that researchers in such contexts are able to maintain strong control over the knowledge production process, even while engaging in boundary-crossing transactions. In the below section, I will therefore seek to understand why and how academics in ‘elite’ departmental contexts come to exhibit these distinctive features. Similarly, I explore how Formal sciences combine a very ‘unbounded’ relation to the ‘social context’ (indicated by the high value of 3.92) with a very ‘bounded’ relation to the ‘knowledge content’ (indicated by the very low value of 1.46). And, to take an example from the ‘orientation of discipline’ dimension, I explore how and why basic/applied disciplines are associated with essentially the converse of the Formal sciences, having a very ‘bounded’ relation to the ‘social context’ (indicated by the low value of 3.06) and an ‘unbounded’ relation to the knowledge content (indicated by the high value 1.78).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Context dimension | Category | Social Context | Intermediary | Knowledge Content | **Total** |
| Institutional context (departmental status) | ‘Elite’ | 3.61 | 2.15 | 1.45 | **2.4** |
| ‘More’ prestigious | 3.4 | 2.46 | 1.54 | **2.53** |
| ‘Less’ prestigious | 3.49 | 2.63 | 1.78 | **2.69** |
| Epistemic context (branch of science) | Life | 3.17 | 2.42 | 1.72 | **2.48** |
| Natural | 3.44 | 2.39 | 1.65 | **2.52** |
| Formal | 3.92 | 2.46 | 1.46 | **2.64** |
| Epistemic context (orientation of discipline) | Basic/Applied | 3.06 | 2.3 | 1.78 | **2.4** |
| Basic | 3.24 | 2.37 | 1.52 | **2.43** |
| Applied | 3.95 | 2.52 | 1.55 | **2.71** |

Table 37. Typology values by contextual dimension/categories and research dimensions

### Institutional context (departmental status): variation by ‘ownership’ of knowledge production

There are three categories of institutional/departmental context, which I classify as ‘elite’, ‘more prestigious’ and ‘less prestigious’. ‘Elite’ departments were defined as (i) being based in a university in the top two of Boliver’s (2015) four status-based ‘tiers’ *and* (ii) having a relatively high ‘Overall’ rating in *REF2014* (relative to competing departments nationally). ‘Less prestigious’ departments were defined as (i) being based in a university in the bottom two of Boliver’s four ‘tiers’ *and* (ii) having a relatively low ‘Overall’ rating in *REF2014* (relative to other departments nationally). Finally, ‘more prestigious’ departments are any which do not fit into categories of ‘elite’ or ‘less prestigious’.

As Table 37 shows, ‘elite’ institutional contexts stand out by having the lowest values out of all nine categories in the ‘intermediary’ (2.15) and ‘knowledge content’ (1.45) research dimensions, as well as having the joint lowest total value (2.4). By contrast, ‘less prestigious’ departments have the highest ‘intermediary’ value (2.63) and joint highest ‘knowledge content’ value (1.78). This suggests that these aspects (activities/attributes) of research are strongly ‘bounded’ within academic control in ‘elite’ departments, and relatively ‘unbounded’ in ‘less prestigious’ departments. I will explore these findings below.

#### Variation by ‘control’ over research collaborations

The greater ‘boundedness’ associated with ‘elite’ departments’ research, indicated in Table 37, became apparent in the high level of ‘ownership’ over the knowledge production process that researchers in ‘elite’ departmental contexts exhibited as they transacted across boundaries and interacted with non-academic collaborators. One manifestation of this was the relation to collaborators and users. Analysis of documentary and interview data related to the four BoRs produced by the two ‘elite’ departments in my sample reveal significant power generated by its prestige and expertise, in the sense that, rather than chasing potential users, researchers in these contexts tended to experience external collaborators/users (primarily industry) being the ones to make the effort to engage with academic research on the university’s terms. There is good evidence of this in at least three of the four BoRs from ‘elite’ departmental contexts: the high demand from the construction sector for consultancy and collaboration with the University of Sheffield’s Vibration Engineering Section (since moved to the University of Exeter); the interest from the steel and defence sectors in the expertise at the University of Cambridge Department for Materials Science and Metallurgy; and the widespread participation of water companies in the University of Sheffield’s ‘Prediction and management Of Discolouration in Distribution Systems’ (PODDS) project. Interviews with respondents from ‘elite’ departments corroborate this analysis:

“We have a lot of industry supporters who are very keen to work with us. We don’t have any trouble finding users.” (Respondent from ‘elite’ department)

“...we’ve said [to the sector] ... *“The onus is on you to come to us and give us the data to work with, because the more you put in, the more you get out.”* And they all approach us, most of them want to be involved.” (Respondent from ‘elite’ department)

This contrasts with many experiences of ‘non-elite’ departments, where there is evidence of academics in these departments having to go to greater effort to attract external support and interest. For example, researchers in the ‘non-elite’ (‘more prestigious’) departmental context of the School of Chemistry and Chemical Engineering at Queen’s University Belfast established the Queen’s University Ionic Liquid Laboratory (QUILL), which was pivotal in the research associated with BoR8.2 (‘Mercury Capture Technology for the Global Petroleum Industry’). QUILL is run as a university-industry consortium, a ‘boundary structure’ serving to signal the department’s industry-relevant expertise and to provide a channel through which industry can let their research needs known. Although highly effective as a means for ensuring the relevance of research, it inevitably means “ceding some control” (Rosinger, Taylor, Coco, & Slaughter, 2016, p. 45) over the direction of academic research: QUILL explicitly focuses on research topics “requested by our industry partners” (QUILL website[[21]](#footnote-21)), under the co-directorship of a ‘boundary-spanner’ who worked in the petroleum industry for over three decades before being given an academic appointment. Moreover, rather than attracting industry interest and collaboration relatively easily, as was apparently the case in the above ‘elite’ departmental contexts, there is more evidence of a struggle to garner initial support for QUILL[[22]](#footnote-22).

To take another example, the case of BoR11.1 (‘Clinical outcome modelling saves lives’), which is based in a ‘less prestigious’ department (and which was discussed in-depth earlier as one of the three illustrative case studies) is arguably an even stronger instance of a department ceding control to an external research agenda-setter. The lead academic researcher involved had served most of his career as a non-academic researcher with a physics specialism in the NHS, before taking an academic post in the university’s Faculty of Technology specifically in order to continue and consolidate a partnership between the University of Portsmouth and Portsmouth Hospitals NHS Trust. In this case, the needs of the non-academic collaborating institution significantly influenced a broad strategic area for the university department.

In a final example, the collaboration was initiated by the university simply being responsive to circumstance. A doctoral graduate from the ‘more prestigious’ departmental context of the School of Mathematics and Statistics from the University of Glasgow was employed by the multinational oil and gas company, Royal Dutch Shell (hereby ‘Shell’). Although this doctoral graduate was employed for his general background rather than expertise in any specific techniques, it just so happened that a certain statistical methodology he had acquired from his PhD supervisor was found to be very relevant to one of the issues facing Shell, that of monitoring groundwater pollution around sites of oil and gas extraction activities. Through this student, Shell and the university commenced a research relationship which resulted in several co-authored papers, the sponsorship by Shell of another PhD student, and collaboration on a novel purpose-built data analysis software (which has resulted in management efficiencies saving at least $10 million as of 2014).

In the above three examples from ‘non-elite’ departmental contexts, universities are positioned as responsive providers of expertise, and as therefore ceding greater control over their research agendas than in the case of the ‘elite’ departmental contexts. This tentative finding of the relative difference in ownership over the knowledge-production process emerged from considering relations with ‘non-academic collaborators’ broadly defined. But it comes into even sharper focus when ‘collaboration’ is defined more specifically in terms of ‘co-authorship’.

#### Variation in patterns of co-authorship and output

Co-authorship implies an intense and potentially ‘costly’ form of transaction in which ownership of knowledge is shared across the boundaries of academia with actors in other sectors. Figure 14 highlights that such intensive, boundary-crossing collaboration is much more common in bodies of research (BoRs) which are based in ‘more prestigious’ (75% of cases) and ‘less prestigious’ (50% of BoRs) departments than ‘elite’ departments (25% of BoRs) in my sample.

Figure 14. Percentage of ‘co-authorship’ and ‘use-focused outputs’ by departmental status

Figure 14 also contrasts this with a different form of boundary transaction, ‘use-focused outputs’. Although ‘use-focused outputs’ do take account of and cognizance of the needs of external contexts of application, they imply much greater academic control over the knowledge production and knowledge content than is the case with co-authorship. ‘Use-focused outputs’ are therefore more common forms of boundary transaction in situations in which academic boundaries, identity and power are relatively strong. Significantly, 100% of BoRs sampled from ‘elite’ departments exhibit this form of boundary transaction (‘use-focused outputs’), compared with only half from ‘less prestigious’ departments and less than half in ‘more prestigious’ departments. Moreover, just as striking as the ubiquity of use-focused outputs as a main boundary-transacting method of ‘elite’ departments is the broad *range* of use-focused outputs which perform this function. For example:

* BoR13.2 (‘Topical oxygen therapy for wound healing’), at the University of Cambridge Department of Materials Science & Metallurgy, produces patented medical devices;
* BoR13.1 (‘High-performance nanostructured-steel armour’) produces an academic journal article aimed at a broad audience which beyond the author’s narrow specialism aiming to summarise the author’s contributions to theory and application of metallic structures in such a way as to advise a broad range of scientists and potential users in disparate fields about how best to bridge the research-application-commercialisation gap;
* the most influential and valued outputs of research at the University of Sheffield’s ‘Vibration Engineering Section’ (responsible for BoR14.1, ‘Managing full scale dynamic performance of civil infrastructure’) are not academic papers but rather construction guidelines which are recognised internationally and have legal status in the case of court actions;
* one interesting use-focused output from BoR14.2 (‘Management of discolouration in drinking water distribution systems’), based in the same department as BoR14.1, is what I term a ‘bridging concept’, specifically, the academic researchers developed a concept of “cohesive transport” which resulted in a “step change” (according to the university’s REF Impact Case Study submission) in the UK water industry’s understanding and management of water discolouration;
* lastly, researchers at the Cardiff University School of Physics & Astronomy (responsible for BoR9, ‘Astronomical Research and Instrumentation’), whose main research focused on building instrumentation for space satellites and using the data to theorise about galaxy formation, also produced ‘use-focused outputs’ in the form of online tools and resources[[23]](#footnote-23) aimed at presenting findings and relevant science in a user-friendly way to the general public, particularly targeting young people, grounded on a perception within the School that curiosity-based astronomical research is considered incomplete until it is reaches (and hopefully stimulates the interest of) the public.

Both the ubiquity and the broad range of use-focused outputs as a main form of boundary transaction in ‘elite’ departments add weight to the interpretation that the will and ability of such departments to maintain control over knowledge production, even that aimed at achieving non-academic ‘impact’, persists in disparate contexts. Even very applied research in ‘elite’ departments, which might be expected to cede greater control to potential users of research, exhibited a notable ownership over the knowledge content. An interesting quote from one of the *REF2014* submission documents of one ‘elite’ department describes the department’s goal as to advance “fundamental engineering research”. Although an interview respondent from this department first reacted to this expression somewhat cynically when I asked what it meant to him, responding that “it sounds like a REF statement (*laughter*)”, he afterwards reflected that

“...well, yes, the ‘fundamental’ bit does come from really wanting to understand what’s happening, what is causing these problems. ... So there is a scientific aspect, so in that sense you could say it’s ‘fundamental engineering’ based on that.” (Applied scientist, ‘elite’ department)

This notion of “fundamental engineering research”, which is similar to the idea of “fundamental technology” used by the OECD’s Centre for Educational Research & Innovation (CERI, 1982, p. 144), describes well the applied research I studied from ‘elite’ departments. The research in such departments, when compared with that in ‘non-elite’ departments, more consistently fit within an academic discipline or sub-discipline so that, although sometimes conducted in close proximity to the context of application, it would rarely enter a ‘transdisciplinary’ mode. That is, the experience of academics in ‘elite’ departments was that their (sub-)disciplinary expertise was necessary and sufficient to act as legitimate figures of authority on the non-academic issues at hand. By contrast, researchers in ‘non-elite’ departments experienced something different: expertise in a (sub-)discipline was necessary, but *not* sufficient. Instead, their legitimacy as figures of authority in a context of application was contingent on entering into “novel configurations” (Nowotny, 2005, p. 28) of scientists and experts which were more transdisciplinary in nature (with the cases of BoR5 and BoR11.1, both discussed earlier in this chapter as in-depth illustrative case studies, being just two examples)

#### Control and confidence in ‘elite’ departments

Another more general manifestation of the distinction between ‘elite’ and ‘non-elite’ departments relates to their experience of realising and evidencing impact submitted to *REF2014*. Although all of the researchers I interviewed hoped that their research would benefit society, a clear distinction emerged in terms of the perceptions of ‘impact’ in *REF2014*. Researchers in ‘elite’ departments were relatively cynical about, or at least unmoved and unmotivated, by the inclusion of impact in the REF. However, with their strong levels of ownership over the research they produced (in the form of ‘use-focused outputs’), researchers in these ‘elite’ departments were confident in their ability to evidence their impact and make the most of the opportunities that it presented:

“A lot of people don’t like the REF and its focus on impact. ...But if we’re sufficiently creative and inventive we can put a spin on what we do or do it a bit differently or do something more in addition to show how what we do, although it is not necessarily driven mainly by impact, still does have impact. ...For example most of what we did for this Impact Case Study, we probably would have done some of it anyway. But because of the REF we were guided to do it in a more structured and organised manner. ...So although it doesn’t sit very well with me philosophically, having to justify everything through impact, I think, practically, we can work with it. …You have to work within the system and we’re happy to do that.” (Basic scientist, ‘elite’ department)

“Although I’ve always been driven by the practical benefits of the work, ‘impact’ in the REF sense is not something I drive towards. It’s more an academic hoop to jump through. But if all it takes is a bit of gathering and passing on information and that helps our impact in the REF, then brilliant.” (Applied scientist, ‘elite’ department)

This contrasts in two main ways with researchers in ‘non-elite’ departments. First, there was more evidence that researchers in non-elite departments, particularly in ‘less prestigious’ departments, felt positively about the impact agenda and were pleased that ‘impact’ was being recognised and afforded status:

“In my case it [the introduction of ‘impact’ in the REF] was positive because ... it allows me to do the research I want to do anyway which makes benefits and impacts. It is more valued now so from my point of view it’s a positive thing. ...Whereas before you had to thinking *‘how can I get published’*, now you’re allowed to think *‘how can I demonstrate impact’*. So ... the consultancy, the training, everything I’m doing now becomes more relevant and recognised.” (Basic/Applied scientist, ‘less prestigious’ department)

“Now with the REF having made it [impact] really important, this institution can focus on impact in a way that it couldn’t really have afforded to do ten years ago. So I think impact particularly fits with a new university like ours which likes to think of itself as being close to business and communities. ... [T]his institution and my work have both probably benefited from it.” (Basic/Applied scientist, ‘less prestigious’ department).

“There are still some people who ... are not interested in impact at all, but for us, that’s what we’ve always done, so for us it [the impact agenda] fits very well. And it has actually made us much more recognised across the university, as this agenda has been increasing... [The university] are very well aware of the value of having us and our ability to feed into impact studies but also other public engagement, we quite often get media stories out there, all this helps, helps bring in good students and helps raise awareness.” (Basic scientist, ‘more prestigious’ department)

But secondly, and somewhat paradoxically, academics in ‘non-elite’ departments, with their more co-produced research which involved input from various organisations and stakeholders, were in fact less certain in confidently asserting that their contribution *had* been responsible for the claimed impact:

“We were invited to a meeting [with a policy advisory body]. ... But although you give them the evidence, you don’t always know what they’ve really taken into account when they make their decisions, because there’s different influences, not just the ... research, but also political agendas.” (Basic/Applied scientist, ‘less prestigious’ department)

“We were invited to a meeting of civil servants, some policy advisers, and all the stakeholders, and this time the minister was there. ...Anyway, with these Impact Case Studies, you have to try and demonstrate that you’ve actually changed something then you get a big tick ... but really I was quite the ‘token’[[24]](#footnote-24) scientist.” (Basic scientist, ‘more prestigious’ department)

#### Summary

In sum, researchers in ‘elite’ departments appear to have a distinctive experience of crossing and confronting academic boundaries when compared to those from ‘non-elite’ departments. ‘Elite’ departments exhibit greater levels of ownership over their knowledge content and this manifests in the ways in which they ‘transact’ across boundaries, primarily taking the form of outputs aimed at specific non-academic users, rather than collaborating with users in the production of knowledge. The specific context of the UK ‘impact agenda’ as institutionalised in the REF therefore draws out the distinction between ‘elite’ and ‘non-elite’ departmental contexts.

### Epistemic context (branch of science): variation by expertise of external collaborator

I distinguish between three branches of science – the life sciences, the natural sciences and the formal sciences (how these were defined and who the sampled departments and BoRs were categorised by branch of science was discussed in the Methodology, Chapter 3). The data in Table 37 (p. 136) suggests broad variation in the ways in which research in different branches of science strike a balance between crossing and maintaining academic boundaries. I will explore these differences below.

#### Variation in the challenges faced (particularly between Formal and Life sciences)

Research in the Formal sciences was found to exhibit the interesting combination of very high ‘social context’ values and very low ‘knowledge content’ values, whereas research based in the Life sciences exhibited the opposite features. The way that interview participants spoke about their research and the ‘boundary transactions’ which brought them into contact with significant non-academic actors, helps shed light on these results.

Interviewees from the Life sciences (including where the discipline was interdisciplinary in nature, classified as Life/Natural) talked about the significant effort and sometimes difficult challenges associated with interacting with non-academic actors. In particular, achieving shared understanding and trust was considered to be a necessary but very complex process which needed to be constantly worked on, particularly since Life science research typically touches upon issues of significant human relevance, such as health and the environment. For example:

“You need to gain trust of everyone you work with and accept that you have to do something for them, that clearly benefits them, even though sometimes they’re not ready or willing to see that.” (Life scientist)

“The ‘realpolitik’ of this gets very messy ... And with such a political climate, trust is essential to our work, and that only comes through long-term commitment.” (Life/Natural scientist)

What makes this so challenging and, from the boundary transaction perspective, so ‘costly’, is that the social, political and scientific issues all combine to create very complex situations in which various actors with different interests and sometimes little or no scientific background all have a legitimate stake in the research, its interpretation and its implications. Many life scientists discussed issues with communicating to broad audiences:

“I have to work with a lot of policy people, government employees, NGOs [non-governmental organisations], and some of these people are very naïve when it comes to the implications of these scientific issues. But I have to find a language which reduces some of this complexity and package it for them logically so that they can learn. ... But it’s no surprise they find it difficult because it quickly gets quite technical. And we bring together different disciplines here ... so even some of us are a bit hazy on some of it sometimes.” (Life scientist)

“It’s really hard to explain this stuff, most people just don’t understand it. I’m not even sure I do fully. So that’s a challenge. I wouldn’t say we’ve overcome it but that’s why we’ve got to keep communicating as well as we can all the time.” (Life/Natural scientist)

#### Life scientists in contested spaces

Academics, particularly Life scientists (according to my interviews) were often faced with a difficult balancing act between maintaining an objective and neutral stance and being more proactive in terms of arguing that the science suggests a given policy. Different Life scientists reported very different approaches to this dilemma: some adopted a strict scientific standpoint whereby the academic would make a point of not advising on policy but only on policy implications; others considered themselves activists or lobbyists. The following two quotes exhibit both perspectives:

“You find yourself in the middle of very enthusiastic political debate, with vehement beliefs on one side and the other. And then there’s people like me who try to put that to one side when doing the science. So you’re under fire from both sides. ...You’re ploughing the middle way through the interest groups which are quite polarized. … And we provide the information. And not everyone agrees with this, but for me I’m absolutely clear that we provide the science, we don’t advise on policy.” (Life scientist)

“I am speaking effectively as an ‘activist’ rather than a ‘scientist’. And I think that’s a blurred distinction for a lot of us. ... The reason I do it [aim to achieve impact through research] is not because of an academic identity, and in some ways the academic identity gets in the way, but it’s more as an ... activist. ... You have to suggest action which means you step across that line between disinterested science and advocacy.” (Life scientist)

The broad public interest of some of the topics that Life scientists in my research focused on can be evidenced by the attention of mainstream media. A few of my respondents discussed the challenges that media attention and media communication could bring. For example, it was considered very difficult to ensure academic research is accurately and objectively portrayed by the media:

“The way the media want you to give a message is very black and white, but in science it’s never black and white. ...They want to know – *‘Is it dangerous or not? Is it worse or better…?’* But “worse” in terms of what? ... As a scientist it is difficult to give a message that is accurate because the media just wants to turn it into headlines.” (Life scientist)

“The media are always happy to run with anything on these kinds of topics, ... the good news and the bad news. One of our papers made the front page and the headline referred to a ‘miracle’… [But it has] also been constantly in the press with … suggestions of all sorts of negative things as well.” (Life scientist)

And the contested nature of some Life science topics meant that academics also had to be careful about how their research was portrayed by the media. For example, accepting funding from certain funders was considered risky:

“Some research carries what the university calls ‘reputational risk’. …And that actually happened in this School. Some journalists found that some guys here ...were analysing some data from a project ... which was originally funded by [controversial industrial sponsor, name removed]. Suddenly this hit the front page of a tabloid and the University went ape-shit. ... There are definitely some situations where I would say ‘no’ [to an offer of research funding]... I haven’t done so yet but I know it could happen.” (Life scientist)

#### The relative simplicity for Formal scientists

The complexity of boundary transactions in the Life sciences as highlighted in the above quotes contrast greatly with those from interview respondents in the Formal sciences. The Formal scientists in my sample overwhelmingly interact with specific industries, rather than with multiple and potentially conflicting stakeholders. Quotes from Formal scientists highlight the relative ease with which they interacted with key collaborators. For example:

“I think the technical challenges of working with industry are manageable, the personal challenges are manageable. I don’t find any issues.” (Formal scientist)

Other respondents who expressed similar views also gave greater insight into why the challenges were so few. The main factor was that although their collaborators, or ‘co-transactors’, were based in non-academic sectors, they predominantly had very significant academic skills and contacts, the vast majority holding PhDs and having maintained links to their universities. As one explained:

“Most if not all of the particular group that we worked with had PhDs and many will have ongoing links with different university departments, so they would understand the research environment of a university and the mode of operation if you like.” (Formal scientist)

Another respondent’s experience vividly illustrates the point that shared expertise and intellectual interest can greatly help to overcome potentially significant barriers associated with different institutional interests:

“We work with a lot of companies all in the same sector ... and it is competitive because they’re trying to guard what they’ve got. But when we work with them, we’re working typically with the companies’ engineers, not the managers or the accountants or what have you, and they [the engineers] have all got similar needs and we provide a forum where we all share ideas together, and they’re not worried about being competitive, it’s an open discussion.” (Formal scientist)

In the above respondent’s case, the shared intellectual interest and expertise between the university and the industry not only helped to overcome university-industry relationship challenges, but also helped overcome barriers to collaboration between industry competitors. The university offered a space in which competitors could meet as a kind of community of practice integrated by a common industrial problem that was best faced by collaboratively pooling data and resources together – in this case, via the disinterested and trusted channel of the university.

#### Natural scientists: mixed experiences

Researchers in the Natural sciences (including where the discipline was inherently interdisciplinary, classified as ‘Natural/Formal’) exhibited elements which fell somewhere in between the experiences and perceptions of Formal and Life scientists. For example, the following Natural scientist, although speaking positively about the relationship with industry, expressed this positive experience with somewhat greater qualification than those interviewees in the Formal scientists. He said:

“We have some really good partnerships with big companies. And that’s perfectly good because it’s not an artificial partnership, we’re not just bringing them in because we have to. They can actually add something because of their particular expertise, and that strengthens our case for research funding. So now we have a joint academic-industrial partnership mode ... rather than the purely academic that we did before.” (Basic Natural Scientist, ‘elite’ department)

So, in the above account, the relationship with industry is not necessarily the only or most obvious way to go, as was the case for Formal scientists. But rather it was more context-specific; they “add something because of their particular expertise”. Moreover, although ultimately giving a positive assessment of industry collaborations, the same respondent explained later in the interview the difficulty he sometimes faced in overseeing collaborations:

“So it was my job to manage the consortium. That involved … multiple industries, multiple institutes, and lots of individuals, scientists, engineers, managers, specialists of all kinds. So you can imagine that’s a recipe for continuing anguish, pain, crisis, that’s just the way it works. We used to talk about the ‘crisis of the day’, the ‘crisis of the week’, and the ‘crisis of the month’, and generally we were working on all three of them at the same time. And that’s the way this kind of research works. Because it’s very complicated politically, very complicated sociologically, and very complicated technically and scientifically.” (Natural scientist)

Another respondent also had equivocal experiences of external collaboration. On the one hand, he had multiple experiences of successfully working with individuals or small private companies in order to produce new technologies and devices for different sectors. But he also had many negative experiences along the way:

“Initially we had ... nobody who believed us. They didn’t believe that it could work.” (Natural/Formal scientist)

And describing earlier experiences of working with industry:

“Large companies sometimes just take the idea and then, unless they really need you to develop it, you don’t hear from them again. ...They just steal your ideas.” (Natural/Formal scientist)

#### Different kinds of collaborator amongst the three branches of science

Interestingly, this pattern whereby Formal scientists tended to have relatively simple boundary transaction experiences, Life scientists have more complex experiences, and Natural sciences exhibit elements of both, maps precisely onto a statistical finding relating to the educational qualifications of non-academic collaborators (co-authors). Figure 15 show that nearly all sampled bodies of research (BoRs) based in the sampled Formal sciences exclusively involve collaborators who have PhDs, with only around 12% of these BoRs involving a collaborator without a PhD. By contrast, nearly half of the BoRs in Natural sciences and more than half of the BoRs in the Life sciences involve collaborators without PhDs.

Figure 15. Percentage (stacked) of BoRs collaborating with non-doctorate holders by branch of science

#### Summary

The data presented here therefore suggests that when researchers in Formal sciences collaborate with non-academics, it is almost exclusively with non-academics with whom they share scientific backgrounds and expertise. The vast majority of these external collaborators have a doctoral qualification and continuing links to academia. This allows far smoother and less ‘costly’ boundary transactions than is possible in Natural and, in particular, in the Life sciences, where academics more frequently interact with non-experts and a more disparate group of stakeholders as they transact across boundaries. To draw on Bernstein’s (2000) concepts, researchers in the Life sciences are able to communicate via ‘restricted’ code – a shortened, “intimate and immediate” (Moore, 2013, p. 66-67) form of communication exhibited within a group of people who can take for granted a significant amount of shared prior knowledge and understanding. By contrast, researchers in other branches of science must more frequently communicate using ‘elaborating’ code (Bernstein, 2000; Moore, 2013), which is more intensive and aims at coming to the kind of shared understanding that ‘restricted’ code assumes.

The relationship between a branch of science and the areas of social or economic life in which that science might have application shapes the kinds of actors with whom academic researchers must transact. To a notably greater degree than in the Natural or Life sciences, the non-academic collaborators with whom Formal scientists’ boundary transactions occur have strongly academic backgrounds consisting of a PhD, as well as strong personal and intellectual ties to academia. In short, boundary transactions in the context of the Formal sciences may barely be experienced as boundary transactions at all. It may make more sense to conceive of boundaries *extending* and *merging*, thereby greatly reducing transaction ‘costs’ almost to the levels of intra-institutional communication. There is an extensive flow of highly academically trained graduates who bring academic skills, networks and inclinations into non-academic knowledge-intensive sectors, from within which these individuals have the capacity and incentive to demand, absorb, apply and occasionally even collaborate on new academic science. As these academically trained and academically inclined doctoral graduates move into non-academic contexts, they simultaneously *extend* and *merge* academic boundaries into/with these non-academic contexts. This creates a new space, a kind of ‘free trade zone’, where ‘low-cost transactions’ can take place between similarly minded individuals, both of whom can simultaneously contribute to one another’s institutional missions without significantly threatening the distinctive identity and core boundaries of either institution/mission.

### Epistemic context (research orientation): various systems of knowledge (production)

The *research orientation* dimension is different to the other two, *departmental status* and *branch of science*, in that the latter two are more solidly grounded in an external reality: departmental status is grounded in the reality of institutional hierarchies (Boliver, 2015), while branches of science are grounded in their focus on distinct phenomena (that is, distinct objects of study) (Bernstein, 2000; Young, 2008). By contrast, *orientation* to knowledge is a looser concept. Research in all disciplines can shift quite rapidly from being focused on ‘understanding’ (Basic science) to ‘use’ (Applied science), with an increasing number of researchers self-defining their work as having elements of both (Hughes et al., 2016; Stokes, 1997). Hard distinctions quickly break down. Although disciplines such as mathematics, physics, chemistry and biology may still, in general, be considered Basic disciplines, this categorisation may not accurately depict much of the research conducted by mathematicians, physicists, chemists and biologists, which is often use-oriented. Similarly, Applied disciplines, such as medicine and computer science, may necessitate advances in fundamental and abstract understanding, say in life systems and in logic. Recognising the imperfect and heuristic nature of these categorisations, my analysis will treat the identified variations between BoRs from Basic, Applied and Basic/Applied disciplines as indications of different systems or regimes of knowledge (production) within which universities function, with different implications for academic boundaries. Specifically, I will show that:

1. the Applied disciplines in my sample highlight universities’ position in a ‘Mode 2’ system of knowledge production which tends towards a ‘post-academic’ science, which sees an increasing number of academics being incentivised to apply their scientific and problem-solving expertise to localised contexts to generate specific outcomes for specific actors (Gibbons et al., 1994; Ziman, 1996);
2. the Basic disciplines in my sample highlight universities’ participation in a broader ‘technoscientific’ system in which academic research is a factor of the success of national and international efforts to mobilise science and technology for broad political agendas, for example those associated with national security and economic competitiveness (Latour, 1987, p. 162; Leydesdorff, 2012, p. 32; Slaughter et al., 2002, p. 286; Ziman, 1996b, p. 313);
3. lastly, the Basic/Applied (use-inspired basic) disciplines in my sample highlight the centrifugal forces associated with the natural advancement, proliferation and fragmentation of new scientific (inter-/multi-)disciplinary (sub)fields which is constantly finding, in the natural world, new objects of (disciplinary) study (Bernstein, 2000; B.R. Clark, 1983b, 1996; Durkheim, 2013).

#### Applied sciences: ‘mode 2’ knowledge production

I will start by discussing research from the Applied disciplines in my study. As Table 37 (see p. 136) showed, the extent of the ‘unboundedness’ of Applied research stands out, not only among the three categories in the ‘Disciplinary orientation’ dimension, but among all nine categories in all three dimensions, receiving a very high total typology value (2.71). This was based mainly on the very high ‘social context’ value (3.95). Unsurprisingly then, Applied scientists interviewed as part of my study placed very significant value on practical outcomes as a marker of research success. For example, one Applied scientist, reflecting on his field, explained:

“It’s an applied subject. To be of any good, somebody has to use it. ...My thinking is, if it helps one [person] I’ll be pleased.” (Applied scientist, ‘elite’ department)

Another explained how he focused his dissemination efforts on specific individuals who would be most likely to use his work in the intended way, ignoring others who may potentially have an interest:

“There’s tonnes of others who might be interested in the work we do but ... the people I want to influence are clinicians. … If the work isn’t clinically relevant it’s kind of pointless.” (Applied scientist, ‘less prestigious’ department)

One Applied scientist explained how being ambitious about maximising the impact potential of research helped with funding bids:

“If you really want to avoid all these negative consequences [of a specific medical condition], then the best thing to do is stop it in the first place, otherwise you’re always fighting against the tide. ...That is why our proposal won the bid – because we were the only group who wanted to design a study from *before* any problems had been diagnosed.” (Applied scientist, ‘more prestigious’ context)

One respondent even felt that his latest work, which built on that associated with the *REF2014* Impact submission, had taken the goal of achieving practical outcomes so far that he no longer considered it to be ‘research’:

“I want to help people get as good an experience as possible for as cheap as possible, that was always my end goal... And now it’s trying to deliver those ideas. ...So we’ve tried to move away from a key ‘research question’ and we’re offering more of a delivery of findings, so it’s not research-oriented as much.” (Applied scientist, ‘elite’ department context)

According to these responses, Applied scientists in my sample were strongly committed to real-world impacts and adopted a ‘what works’ approach to achieving them, prioritising outcomes over scientific findings. To them, this did not just mean the successful conduct of ‘applied’ research which was judged scientifically rigorous by peers; rather, it meant tangible benefits to clinicians and patients, industry and customers, etc. They often had very specific intended outcomes in mind. For example: BoR14.2 (‘Management of discolouration in drinking water distribution systems’) did not just aim at research into the causes of water discolouration, but worked directly with the industry engineers and management to help institute management, monitoring and response procedures with *the specific intended outcomes* of improving the experiences of water users and reducing the burden of dealing with customer complaints for water companies. Similarly, BoR11.2 (‘Improved mobility and quality of life for children with disabilities’) did not just aim to improve the artificial intelligence in automated wheelchairs for children, but went to great lengths to ensure close input from child users and related professionals, such as staff at ‘special schools’ and health care professionals, in order to achieve specific improved user experience targets. BoR13.2 (‘Topical oxygen therapy for wound healing’) did not just aim to show ‘proof of concept’ that hydrometallurgy concepts could be used to generate flows of oxygen (which it is known is helpful for would healing), but was specifically driven by the motivation of healing patients with chronic wounds – the resultant device was indeed found to be able to heal chronic wounds and ulcers, in one case healing a ten-year-old wound.

The research in these Applied disciplinary contexts thus display the ‘mode 2’, at times almost ‘post-academic’ characteristics of prioritising the use and impact of research over the theoretical relevance or depth of understanding achieved by research. Disciplines are fonts of knowledge and methodologies, and may be a source of identity and commitment, but they are not drivers or organisational anchors of research efforts. Rather, in the research I have sampled from Applied disciplines, scientific expertise and effort is co-ordinated around the integrating principle of collaborating to find transdisciplinary solutions to localised social, economic and technological problems.

#### Basic/Applied (use-inspired basic) disciplines: proliferation of academic knowledge

Research in the Basic/Applied disciplines in my sample exhibit very different characteristics from Applied science. This is indicated by the very different typology values, with a very low ‘social context’ value (3.06), low ‘intermediary’ value and very high ‘knowledge content’ (1.78) (see Table 37, p. 136). This difference did not lie in the motivations of researchers from Basic/Applied disciplines, though, who, like those in Applied disciplines, were clear that they wanted their research to have benefits in the real world. For example:

“When I do research, it’s not just about the publication, I really want to help.” (Basic/Applied scientist)

“I’m quite idealistic. I’m working in this area … because I’m concerned about the situation… The early part of the work in terms of impact was essentially a hobby, I wasn’t getting paid to do that. … But I’m fortunate to be in an institution that has always tolerated impact.” (Basic/Applied scientist)

What explains the low typology values, then, is the indirect and long-term nature of the use-inspired goals in Basic/Applied disciplines. Rather than research oriented towards achieving specific outcomes for specific actors, as was the norm in research sampled from Applied disciplines, research from Basic/Applied disciplines was focused, in the main, on advancing thediscipline in the first instance. For researchers in these disciplines, the way to achieve impact was to contribute to the discipline, because long-term impact depended on the strength of the body of knowledge defined by the discipline. Researchers were aware that such an approach, although ‘use-inspired’ in the long run, could sometimes mean periods of “unapplied” research, in the words of one respondent:

“I’ve been working on this since 2002 and for the first several years of that it was very unapplied… We [the discipline] didn’t understand something, and I wanted to understand it.” (Basic/Applied scientist)

Similarly, another respondent recalled that:

“When I first did my study here I did more like a lab-based study, and I was thinking, okay, it’s an ‘applied’ area, and I might get a ‘significant result’, but in terms of impact, is that really making a difference in everyday life?” (Basic/Applied scientist)

This Basic/Applied approach to achieving research-based impact through contribution to a use-inspired basic discipline rather than localised projects in the context of application (as was the norm in sampled research from Applied disciplines) had an interesting implication for the nature and epistemic content of the research. Research from Basic/Applied disciplines was much more explicitly engaged in *theory* work: disciplinary theory, or at least a certain kind of disciplinary theorising, was a significant part of the link between abstract academic science and application in real world contexts.

This importance of theory as a pathway to impact can be seen in the importance of ‘bridging concepts’ in Basic/Applied research. As explained earlier, these are concepts which condense underpinning scientific research and theory into a more readily understandable concept so as to be suitable for consideration and application by non-specialist users and stakeholders (and as such ‘bridging concepts’ can be understood as a form of ‘use-focused output’). One such bridging concept, that of ‘serotonin syndrome’, was discussed earlier in the extended illustrative discussion of BoR4.2 (‘Informing MDMA policy’). Another is that of ‘assimilative capacity’ in the Basic/Applied context of BoR7.1 (‘Defining and Sustaining Healthy Seas’) based on research by the Centre for Environmental and Marine Sciences and Services (CEMaSS) at Edinburgh Napier University. CEMaSS’ work had significant relevance to environmental regulations and responsibilities under the European Union. One of the goals of their researchers was to provide policy actors with a concept which was grounded in rigorous science about the health and sustainability of European seas, but which was also readily understandable and usable by non-scientific policy actors. CEMaSS put forward the concept of ‘assimilative capacity’. The ‘assimilative capacity’ concept summarises a scientific model which assumes that all natural environments have the capacity to assimilate some level of acceptable change, and that only change beyond this level should be considered unacceptable. The ‘assimilative capacity’ model aimed to provide a formula for ascertaining what level of change a given region or environment could acceptably assimilate. CEMaSS were thus proposing a model which accounted not only for the latest oceanographic science but also for political realities, such as current regulation and the inevitability of clashing socio-economic interests (such as between regulators and farmers whose agricultural waste may contribute to changes in the ‘changes’ in European seas, since agricultural waste can lead to an increase in phytoplankton on water surfaces with the result that less sunlight penetrates below the surface, with potentially negative effects on sea life).

This greater preoccupation with theory also came through in the interview data, as respondents from Basic/Applied disciplines explicitly conceptualised their work in terms of linking theory to practice in a way that other respondents did not. For example,

“Whether it’s teaching, training, consultancy, research, whatever, I’m working with theory, but at the same time always thinking how to make sure the theory is relevant. The transfer from theory to practice and the links between theory and practice, as well as to policy, are really important to me.” (Basic/Applied scientist)

“My theoretical background ... was originally quite abstract and very scientific... Now, I still work theoretically, but I’ve made the decision to use the theory but to be driven by practical goals.” (Basic/Applied scientist, ‘less prestigious’ department)

Based on this evidence, I see research in the Basic/Applied disciplines in my sample as illustrating academia’s internal drive to continually bring ever more finely classified aspects of the world into the domain of academic knowledge. As knowledge specialisms proliferate, new sub-disciplines, often interdisciplinary, emerge, which have their own theoretical perspectives on phenomena deemed to fall within its purview. Instances of such sub-disciplines in my own sample of Basic/Applied disciplines include *psychopharmacology*, which best describes the discipline of the Drugs and Addictive Behaviour Research Group at the University of East London, School of Psychology (responsible for BoR4.1 and BoR4.2), and *marine ecology*, which best describes the discipline of CEMaSS researchers (responsible for BoR7.1 and BoR7.2). The impact agenda seems to sit well with this internal academic drive, as it rewards sustained (disciplinary) focus on specific aspects of the natural world which have relevance to humanity’s projects and problems.

#### Basic sciences: a technoscientific system

The last category is that of Basic disciplines. According to the typology values associated with Basic disciplines, they are relatively ‘unbounded’ on all research dimensions. It received relatively low values for ‘social context’ (3.24), ‘intermediary’ (2.37) and ‘knowledge content’ (1.52), and, accordingly, a low Total typology value (2.43) (see Table 37, p. 136). In fact, the category of Basic disciplines is the only one among all nine categories across the three ‘contextual dimensions’ (departmental prestige, branch of science, orientation of discipline) which has low values on all three ‘research dimensions’ (social context, intermediary and knowledge content). I will aim to shed light on these findings by exploring the sampled research from Basic disciplines in greater detail.

Two of the key features of Basic science are (i) that it is constantly pushing at the frontiers of current knowledge and humanly-accessible data and (ii) that its discoveries can have far-reaching consequences and implications for a range of different scientific and real-life applications (Ziman, 1984). In the research from Basic disciplines that I have analysed, the main link between (i) and (ii) is *technology*: the desire for new data allowing ever more fundamental insight into various aspects of the natural world fuels the demand for technologies capable of accessing and analysing this data, and it is these technologies that then have potentially wider scientific and real-life applicability. This was recognised by my interview respondents:

“I think about the science rather than who might end up using it. But the hard work is actually the collection and analysis of the data – our science is driven by the data we can collect. So we have the instrumentation group ... [whose] instruments allow us to do much more in terms of the science, but then the technology also gets sold all over the world.” (Basic Life scientist)

“Scientists are always going to be playing around with the latest unproven technology ... but actually there’s a synergy rather than a tension between scientific technology and technology for application. Because although its core science, the components and technology can be used and sold for various other purposes.” (Basic Natural scientist)

This synergy, whereby the demand for technology to drive Basic science converges with the social demand for technologies, underpins university’s participation in the ‘technoscientific’ social order (Latour, 1987, p. 162; Leydesdorff, 2012, p. 32; Slaughter et al., 2002, p. 286; Ziman, 1996b, p. 313) in which powerful political, commercial and defence (military) interest groups aim to “control” (Bensaude-Vincent et al., 2011, p. 366) and “construct” (Schmidt, 2011, p. 104) the social world via technological projects. For example, of the seven bodies of research (BoRs) sampled from Basic disciplines:

* three BoRs produce technologies which contribute to *national security* (BoR5 supported naval operations; BoR8.3 supported the prosecution of dealers of illicit drugs; and BoR9 technology contributes to the European and more global aerospace industry);
* three BoRs contribute to the *energy sector* (BoR8.2 and BoR10.1 both contributed to the oil and gas exploration and extraction industry; BoR9 technology has contributed to international thermonuclear reactor projects);
* and two BoRs do research directly supporting large *pharmaceutical companies* (BoR8.1 produces biocatalysts targeting use in pharmaceutical synthesis; BoR10.2 conducts drug trials for large pharmaceutical companies).

This participation in a technoscientific system became manifest in the forms of boundary transaction associated with sampled research in Basic disciplines. Figure 16 (below) contrasts two forms of people-led boundary transaction across the three categories, Basic disciplines, Applied disciplines and Basic/Applied disciplines. The figure highlights the significance of boundary-spanners (or ‘knowledge brokers’) in Basic sciences – 100% of BoRs from Basic disciplines exhibit this form of boundary transaction. Outreach by contrast is relatively insignificant, with only 38% of Basic BoRs exhibiting this form of transaction. This contrasts with Applied and Basic/Applied disciplines. In both of these categories, ‘outreach’ is a more frequent form of boundary transaction than ‘boundary-spanners’. Uniquely to Basic sciences then, at least in my sample, is a priority of an interflow of experts to and from academic and non-academic settings, as opposed to a more one-way flow of academics only entering into non-academic contexts to disseminate findings or establish demand for their research.

Figure 16. Percentage of BoRs exhibiting different forms of boundary transaction by research orientation

The importance of this point can be seen with greater clarity when seen in context. For example, in BoR8.2 (‘Mercury Capture Technology for the Global Petroleum Industry’) researchers at the School of Chemistry and Chemical Engineering, Queen’s University Belfast (QUB), had a long history of expertise in ‘ionic liquids’ (liquid salts). Research from the early 1990s had focused on how ionic liquids could be used as ‘green’ solvents (solvents are used to dissolve other substances, and can sometimes lead to by-products which are harmful to humans and the environment) in various industry contexts. Eventually, this led to a significant formal partnership between the School and Petronas, a large Malaysian petroleum company who saw great potential in this use of ionic liquids. A leading scientist with several decades of experience at Petronas was given an academic appointment at QUB, where he is a professor, co-director of an academic spin-out company and also co-director of the Queen’s University Ionic Liquids Laboratory (QUILL) and a key knowledge broker not only between the university and Petronas, but to the wider petroleum industry.

An example of a student/graduate boundary-spanner was already discussed earlier in this chapter, under the section on institutional context (‘disciplinary status’). This was the case of the doctoral graduate from the University of Glasgow School of Mathematics and Statistic associated with BoR10.1 (‘Monitoring Groundwater Pollution’). As explained, the student was the boundary-spanner (knowledge broker) in that he provided a direct link between the School and his new employer, multinational oil and gas company, Shell. Through this student, Shell and the university commenced a research relationship which resulted in several co-authored papers, the sponsorship by Shell of another PhD student, and collaboration on a novel purpose-built data analysis software.

Another example from QUB relates to BoR8.1 (‘Biocatalysts for Industrial and Medical Applications’) and involves both student/graduate and more senior boundary-spanners. Researchers at QUB’s Centre for Theory and Application of Catalysis (CenTACat) have a long-standing expertise in the production of bioproducts through the process of ‘biocatalysis’ (the transformation of organic compounds using enzymes). Biocatalytic processes, and the bioproducts they produce are key to the industrial production of new medicines. In 2015, a new multi-million-pound partnership between QUB and Almac Sciences, a large biotechnology company was announced, dedicated to collaboration on research into and application of biocatalysis. Although this formal ‘QUB-Almac Sciences Biocatalysis Partnership’ is only a recent development, it is underpinned by many years of significant inter-mobility of graduates, academics and industry scientists, characterised by Almac sponsoring PhD students with QUB’s CenTACat, Almac scientists visiting and co-authoring with CenTACat professors and sometimes holding joint academic posts, and, most significantly, Almac Sciences hiring doctoral graduates who studied at CenTACat – the extent of this was such that, by 2014, fifteen of the thirty scientists which make up Almac Science’s ‘Biocatalysis Group’ were QUB graduates (with other QUB graduates having advanced onto more senior roles within the company, all the while maintaining close links with the university).

To summarise, the research sampled from Basic disciplines exhibit relatively ‘low’ (‘bounded’) typology values across all research dimensions, but they nonetheless go onto have significant real-world ‘impact’ because of the ways in which they are embedded into wider technoscientific systems which are driven by knowledge-intensive organisations who may themselves participate in and support fundamental research, but whose priority is the application and exploitation of knowledge for particular purposes. The synergy between scientifically-driven demand for technology and disciplinary experts and the application-driven demand for the same kinds of technologies and expertise means that boundary transactions do not challenge the boundaries of academia, and this explains the low ‘total’ typology value associated with the Basic disciplines in my sample (as seen in Table 37, p. 136).

## Chapter summary

This chapter presented and explained the findings of my analysis. I illustrated the earlier theoretical points made about boundary transactions, that is, how boundary transactions, rather than necessarily implying a weakness in academic boundaries, can be a mechanism for reinforcing academic boundaries. I also showed how the various attributes and activities associated with academic research, derived from McNie et al.’s (2016) typology (see Chapter 2), could be grouped according to their relation to academic boundaries. Certain aspects of the research in my sample, most importantly the goals and outputs and their intended outcomes, were typically focused on the social context beyond the boundaries of academia. Most boundary transactions therefore focused on mobilising interest in the research from actors in relevant social contexts, or disseminating knowledge to potential ‘users’ in these contexts. I classified these attributes/activities of research as the ‘social context’ dimension. Similarly, certain other aspects of the research in my sample were systematically focused on maintaining academic boundaries. These can be understood as those attributes of academic research which are a core part of defining academic boundaries and the academic identity – expertise, learning and human capital. I classified these attributes as research as the ‘knowledge content’ dimension. Only rarely in the sampled research did boundary transactions allow significant outside influence on the ‘knowledge content’ dimension. Thirdly, there are a broad range of activities and attributes associated with research which mediate between the ‘bounded’ relation to the knowledge content and the unbounded relation to the social context. I classified these as the ‘intermediary’ dimension. These were more variable, sometimes being very ‘unbounded’, but sometimes operating to reinforce academic boundaries. Often, different aspects of the intermediary dimensions of research pulled in different directions. Indeed, this is to be expected given the earlier theoretical discussion which stated that a key function of ‘boundaries’ in general is to allow *selective* transactions, such that boundaries *regulate* the relationship between academia and wider society, as opposed to erecting an impenetrable boundary. I provided three in-depth illustrative case studies (BoRs 4.2, 5 & 11.1) to reveal the nature of these three different research dimensions (‘social context’, ‘knowledge content’, ‘intermediate’), and also to give the reader greater insight into how I read, analysed and interpreted the data pertaining to the n=19 bodies of research (BoRs).

I then moved on to a more explanatory analysis. Observed variations in the extent of boundedness in the *research dimensions* (social context, knowledge content and intermediary) across the three *contextual dimensions* (departmental status, branch of science, disciplinary orientation) guided my investigation into underpinning structures and mechanisms which would explain these variations. At this stage of the analysis, I searched from across the full qualitative and quantitative dataset that I had generated, based on documentary sources and interviews, to seek potential explanations. Although analysis revealed that *all nine* contextual categories across the three contextual dimensions tended, overall, towards the reproduction rather than the weakening of academic boundaries, it also revealed that there was variation within each dimension in the extent and nature of the management of boundaries and transactions across them.

First, departmental status influences the experience of academic boundaries and boundary transactions in my sampled research. The main dividing line is between a small ‘elite’ group of departments and the majority of ‘non-elite’ (comprising the categories of ‘more’ and ‘less’ prestigious) departments. ‘Elite’ departments, although often very dedicated to ensuring that their research outputs have relevance to non-academic ‘users’, are able to balance this potential threat to academic boundaries by using their ‘power’ to maintain strong control over the process of knowledge production, rarely allowing ‘outsiders’ to contribute and this allows strong reinforcement. By contrast, ‘non-elite’ departments are often more collaborative and open in terms of allowing non-academics more input into shaping and generating the research. In these departments, boundary transactions therefore often take place deeper within academic boundaries, at the site of knowledge production. This poses potentially greater challenges and even a threat to the reproduction of these boundaries. But, in my analysis, research in non-elite departments also tends, ultimately, more towards reproduction rather than weakening of academic boundaries; the potential challenges of close collaboration with non-academic actors and users do not appear to outweigh the strongly academic scientific objectives and approaches evident in these departments.

Second, Branch of science also influences the experience and extent of academic boundary transactions. The key factor here is the kind of actors with whom academics interact and ‘transact’. Formal scientists typically face far fewer boundary challenges because they almost exclusively transact with actors who have PhDs and have maintained something of their academic identity, bringing academic skills and an academic mind-set into non-academic contexts, where they continue to stay in touch with, apply and occasionally collaborate on academic research. Life scientists in my sample faced more frequent and difficult boundary transaction challenges as they interacted with a broader range of actors, such as policymakers, regulators, the public, the media and commercial actors, most of whom do not have a shared academic background or a shared understanding of scientific issues, but rather have a stake in the interpretations and implications of science. Natural scientists were more mixed, with some instances more in line with Formal science and others more in line with Life.

Lastly, I found that the orientation of the discipline was also a dimension along which academic boundaries and boundary transactions varied. The main factor here is how different disciplines are embedded in different systems of knowledge. Applied disciplines in my sample mainly corresponded to a ‘mode 2’ system of knowledge production which was focused on producing knowledge in the context of application, with a reduced role for academic disciplines. Basic/Applied disciplines represented the underpinning drive of the academic knowledge system to internalise all elements of the natural world into the academic domain by making them objects of theoretical and disciplinary knowledge. Finally, the research associated with Basic sciences were found to be synergistic with technoscientific systems which operates at the level of powerful political, commercial and military interests.

In the following chapter, I will discuss these findings in relation to the empirical and theoretical literature reviewed in Chapter 2.

# Chapter 5. Discussion

## Introduction

My analysis has found that, across all contextual dimensions studied (different institutional contexts, different branches of science, and different disciplinary orientations), research-related academic boundary transactions seem to be tending more towards the reproduction of academic boundaries rather than their weakening. There was variation, however. The balance between transacting across boundaries whilst simultaneously maintaining boundaries was achieved differently in different contexts, and some contexts came closer than others to this balance tipping towards the weakening of boundaries. This chapter will advance the above findings and analysis by focusing on the main explanatory themes that emerged. Rather than focus on explanations that I posited at the level of specific context dimension (departmental status, branch of science, and disciplinary orientation) as I did in the above chapter, I will highlight those explanatory themes which have relevance across different contexts. In particular, and informed by my ‘critical realist’ philosophical approach to social science (see the ‘Methodology’, Chapter 3), I will draw out those explanatory themes which constitute underpinning structures and mechanisms whose existence and processes transcend the empirical objects I have studied. These explanatory themes, I argue, help to explain (i) the overall finding that research-related boundary transactions tend towards the reproduction of boundaries, and (ii) observed differences in the various contexts of academic research studied. The four main explanatory themes are ‘educational function’, ‘academic trajectory’, ‘academic identity’ and ‘power and control over (academic) science’.

The first theme is the ‘educational function’ of universities. The flow-through of students is an essential fact of higher education which transcends the specific instances of student mobility and ‘boundary-spanning’ which were relevant to my sampled bodies of research (BoRs). The argument then is that this underpinning fact of higher education is an important factor in shaping the long-term transformation of the relationship between the research function of universities and the use of academic research in non-academic contexts, as increasing numbers of academically trained graduates populate these non-academic contexts from which they demand and apply academic knowledge. The teaching/training function of universities also had other impacts on the observed research and boundary transactions which I shall note.

I refer to the second explanatory theme as ‘academic trajectory’. This explanatory theme rests on the combination of two distinct but interrelated aspects. The first is the ‘academic trajectory’, the university’s key “*internal* phenomenon”, which is the university’s striving to comprise “the totality of the branches of human learning” (Durkheim, 2013, p. 93, original emphasis), leading to the proliferation of new specialisms which co-evolve with organisational structures, predominantly in the form of departments or research units associated with (inter)disciplinary and sub-disciplinary fields (B. R. Clark, 1983; Gumport & Snydman, 2002). The second aspect is the unavoidability of engaging in boundary transactions, as discussed in the Literature Review (Chapter 2). I will review this in the relevant section below.

The third theme is that of ‘academic identity’. A common theme among several of the academics interviewed was how academic identity – however this was defined – was a resource for overcoming perceived challenges to objectives related to advancing scientific understanding, transacting across academic boundaries, and achieving non-academic ‘impact’. The particular conceptualisation of academic identity which has explanatory and transcendental characteristics is one which must link three distinct categories: the individual academic; the internal dynamic of the university as an institution; and the perception of external actors who see the academic identity as a carrier of credibility and authority (i.e. scientific capital)[[25]](#footnote-25).

The final explanatory theme recalls my overarching interest in the ‘power and control’, here using my earlier analysis to take a broader perspective of forces of power and control over science more generally, albeit with a focus on implications for academic research and boundaries. This emphasises the interacting powers which act upon academia’s boundary transactions from both within and without. Through its broader perspective, this theme acts partly to draw together key points from other themes.

## Explanatory themes

### Educational function

#### Flow-through of (doctoral) graduates

In the Analysis (Chapter 4), the importance of the educational function emerged mostly through the finding that doctoral graduates who move into non-academic, knowledge-intensive workplaces contribute to eased boundary transactions from the university’s perspective. Universities’ educational function, whereby UK universities produce significant numbers of doctoral graduates, the majority of whom leave academia to work in industry or public sector knowledge-intensive contexts (Royal Society, 2010), is a key underpinning reality with significant implications for academic boundary transactions.

Although now in non-academic contexts, these graduates bring with them their significant academic knowledge, skills and “socialisation” into “esoteric” (Bernstein, 2000, pp. 11, 29) knowledge domains with which they have the capacity and incentive to demand, “absorb”, apply and occasionally even collaborate on new academic science (Bishop, D'Este, & Neely, 2011, p. 31). In effect, this creates a situation whereby boundary transactions may not be experienced so much like transactions as simply a collaboration with an academic colleague. Something of academia enters the non-academic, in a sense extending the reach of academic boundaries. This interpretation chimes with other research into ‘boundary-spanning’ students and graduates, which finds that STEMM students see “industrial experience as a tool to achieve … traditional academic goals” (Mendoza, 2007, p. 84). The extension does not necessarily impinge on existing academic boundaries and values, therefore. Rather, it creates a new space, a kind of ‘free trade zone’, where ‘low-cost’ boundary transactions can take place between similarly minded individuals, both of whom can simultaneously contribute to one another’s institutional missions without significantly threatening the distinctive identity or core boundaries of either.

In the Analysis (Chapter 4), this point was initially raised in explanation of why Formal scientists had fewer ‘costs’ and challenges associated with boundary transactions than was experienced by Natural scientists and, in particular, Life scientists; Formal scientists’ external collaborators were almost exclusively doctoral graduates. But as well as contributing to the explanation of observed variations, it also contributes to the explanation of the general finding that boundary transactions associated with the sampled research tended more towards the reproduction of academic boundaries than its weakening. Most bodies of research (BoRs) involved external collaborations primarily with individuals who held doctoral degrees, and in two-thirds of BoRs, external collaborations *exclusively* involved individuals who held doctoral degrees. The educational reality of a highly scientific non-academic workforce with whom academics collaborate was therefore a major influence on the boundary transaction experiences of my sampled BoRs and the academics involved.

#### The teaching/training imperative

This was not the only way in which students/graduates shaped the observed research-related boundary transactions. There were other ways, both direct and indirect, in which the teaching/training imperative of universities shaped the sampled research and research-related boundary transactions.

For example, in two of the BoRs sampled, doctoral students’ research made a key contribution to the impact and related boundary transactions. In both cases, these students went onto work in non-academic contexts where they directly applied their academic research and maintained relationships with their academic institutions. The potential for students to add to the research power and reputation of a senior scientist was in fact often found to be a major draw to academia, my interviews revealed. Four of my ten interviewees who had once worked in non-academic sectors explicitly said that access to doctoral students was one of the reasons they chose to return to academia, while several other interviewees also emphasised the value of access to students.

Moreover, academics’ responsibility to promote the employability of their students often prompted academics to seek boundary-transacting activities that could coincide with their education. For example, a doctoral student who was recruited to contribute to outreach activities associated with scientific communication related to the university’s astronomy research has developed his career as a science communicator since graduation. There were also at least two cases where a significant formal partnership between an academic and non-academic institution was grounded just as much on the student-graduate links from university to the external organisation as it was on the research partnership.

All this chimes with the history of the institutional coupling of education and research within universities. The key factor was not that research-active staff showed themselves to be effective teachers, but rather that research and scholarly productivity of academics was found to benefit hugely from the intellectual and cognitive specialisation demanded by teaching within a disciplinary framework, and from involvement of students in the research process as part of their studies. This can be seen in historical accounts showing that a drive towards the specialisation of academic staff received a boost when Scottish universities experimented with the cost-saving device “of using professors expert in a single subject as lecturers to large classes, a system ... which became general by the eighteenth [century]” (Perkin, 1987, p. 16), and another boost in the nineteenth century when academic scientists in Germany found that a laboratory-based education led by only one specialist academic could prepare multiple students for careers in teaching, research (academic and industrial), and other professions (i.e. pharmacists), whilst simultaneously providing a massive boost to the academic’s own research (Ben-David, 1971, 1977; Ben-David & Zloczower, 1962; Elias, 1982, 1994; Perkin, 1984; Schwartzman, 1984). The pertinent point for my purposes is not just that students contributed somehow to the research or impact. Rather, the more pertinent point is that universities can contribute to their core function of teaching/training by finding ways for students to participate in research-related boundary transactions. To the extent that they contribute to this teaching/training function, universities’ research-related boundary transactions can contribute to the ongoing legitimising of its position as society’s key knowledge institution. This in no way detracts from the concern that students may be vulnerable to exploitation, as has been observed elsewhere (Slaughter et al., 2004). The point is simply that oneof the ways in which research-related boundary transactions can serve to reinforce and reproduce academia’s core boundaries is by using these transactions as opportunities to support their students’ education and development.

### The academic trajectory

This explanatory theme was first highlighted in the explanatory analysis presented in Chapter 4 in relation to the research sampled from disciplines categorised as Basic/Applied. I argued that these illustrate academia’s internal drive to continually bring ever more finely classified aspects of the world into the domain of academic knowledge. However, here I argue that this trajectory is at play more generally, not only in use-inspired basic research and not only in my sample. A historical perspective helps to appreciate this more general relevance.

As sites dedicated in various ways to the “pursuit of knowledge” (B. R. Clark, 1983, p. 12), universities have always experienced pressure from non-academic social actors and institutions to address their knowledge needs. For example, despite arguably attaining greater levels of autonomy than other institutes of learning in other times and places up to that point, medieval European universities were closely tied to and influenced by the demands of church and state, and the main activities of universities were oriented towards the production of professionals entering the service of these institutions and the interpretation and re-interpretation of knowledge pertaining to them (Ben-David, 1971; Durkheim, 2013; Perkin, 1984). Crucially though, even at this time universities’ main contributions to society were underpinned precisely by erecting some form of boundary and creating some level of insulation from society, allowing for relatively independent, critical and internally-driven scholarship (again, largely underpinned by the *educational function*, that is, the demands of fee-paying students). Outputs of critical knowledge, scholarship and students therefore can be conceptualised as early ‘boundary transactions’ through which universities simultaneously established their distinctive institutional identities *and* their valuable social roles and contributions, which depended in part upon this relative autonomy and boundedness. Boundary transactions can similarly be observed in the early modern period, as academic ‘science’, then referred to as ‘natural philosophy’, gradually came to take a more central place in universities and societies. Between the fifteenth and seventeenth centuries there arose, for the first time, notable societal demand for the insights derived from empirical academic scientific scholarship (B. R. Clark, 1984), first from the artists, architects and engineers of Italy, then, even more extensively, amongst the emergent middle class of navigators, merchants and artisans in Northern Europe (Ben-David, 1971, pp. 69, 170).

Given this history, the notion of a ‘Mode 0’ system of knowledge production (Bresnen & Burrell, 2013) has been put forward as a description of the system which preceded ‘mode 1’ and ‘mode 2’, grounded on academia’s responsiveness to external knowledge demands. The ‘Mode 0’ thesis emphasises that scientific disciplines developed through forms of patronage whereby the insulated space for conducting empirical research and constructing bounded disciplinary categories and identities co-evolved with, and relied upon, the willingness of socially powerful actors to sponsor such work. This chimes with some of the empirical findings of my own research and others that where there is promise of a long-term, mutually beneficial relationship, university-industry collaboration can be compatible with and even contribute to “academic freedom” (Slaughter et al., 2004, p. 146) to the extent that it provides the resources and forms of capital which are important to the conduct of good quality science that might otherwise have not been possible. By contrast, these perspectives seem to counter Bernstein’s (2000) analysis, for whom this would represent a ‘weakening’ of academia’s boundedness.

As regards this explanatory theme, the point is not to ‘beg the question’ as to whether this analysis should be interpreted as an indication of stability or change, strength or weakness of academic boundaries. Rather, the lesson to extract is that there are underpinning trajectories which seem to have contributed to the relative persistence and resilience of academic boundaries. These can best be thought of as a pair of trajectories in combination. First is the trajectory originally highlighted by Durkheim (2013) whereby “the university strove and was expected to strive … [towards comprising] a plurality or even the totality of the branches of human learning” (p. 93). For Durkheim (2013), this trajectory of the university has significance “[o]ver and above the external factors which brought it [the university] into existence” (p. 93). The second trajectory is that of academia’s ties to other, mainly knowledge-intensive sectors with which its main boundary transactions occur.

Building on the idea of ‘transactions’, organisational sociologists have developed the idea that academia “*transcodes* external issues and influences into topics of its own” (Kantasalmi & Tuunainen, 2018, p. 340, original emphasis). This well describes my analysis of use-inspired basic fields of research. The tendency towards use-inspired basic research reflects academia’s focus on ever more finely-classified natural phenomena – *the academic trajectory*. But it also embodies universities’ commitment to socially valued boundary transactions. Through use-inspired basic research, real-world issues are turned into objects of academic knowledge and authority. As noted elsewhere, this mostly emerges in research from disciplines which I categorised as Basic/Applied. This category referred to REF2014 Units of Assessment (UoA) which comprised disciplines or disciplinary groupings which are necessarily grounded in both applied and basic orientations. For example, UoA4 includes ‘Psychology, Psychiatry and Neuroscience’ and UoA7 includes ‘Earth Systems and Environmental Sciences’. Both of these disciplinary groupings I judged to have necessarily both applied and basic aspects and therefore aligning closely with the notion of ‘use-inspired basic research’ (Stokes, 1997). But, in line with evidence of an increase in academic use-inspired basic research (Hughes et al., 2016), much of the sampled research more generally exhibited similar characteristics. For example, some of the research sampled from the Basic disciplines of Biology (UoA5), Chemistry (UoA8) and Mathematical Sciences (UoA10) was grounded in use-oriented subfields including marine mammalogy, medicinal chemistry/pharmacology, and environmental statistics, respectively.

As a general finding then, an important part of the explanation of how academia achieves the ‘balancing act’ whereby boundary transactions operate to simultaneously cross and reproduce academic boundaries is the academic trajectory described here. The drive to incorporate ever more finely classified phenomena into scientific sub-disciplines is a distinctive and arguably quintessential feature of academia. That the phenomena brought into academic purview are guided in part by the present needs of society means that this internal academic drive also becomes an effective boundary transaction mechanism.

### Academic identity

‘Academic identity’, although not the focus of my study, ended up being a valuable concept to help understanding and interpreting certain findings. For one, the notion of ‘academic identity’ helps to interpret the way in which many of my participants talked about what they felt they ought to do as academics, particularly when discussing ambitions which require surmounting barriers and challenges. This self-conception of what their role as an academic was provided a motivational resource for these researchers. For example, several felt that it was the role of academics to try and change the world through their research, i.e., generate impact (despite mostly being at least somewhat critical of this term), albeit that they often also spoke of how institutional culture and the wider scientific environment were not set up to maximise the benefits of science. Winning large grants and producing academic journal articles were perceived as being more valued by universities, even though this does not necessarily align with generating impact, which requires effort to be focused elsewhere. Two interview respondents were specifically critical of research councils, who, they argued, often favour research grant proposals that would be extremely rigorous and comprehensive scientifically, but very uncertain in terms of whether the findings will be of any social or economic relevance. But, like some of Watermeyer’s (2016b) participants, my respondents’ sense of an academic identity was a source of motivation to reach out to users and conduct research of relevance to them.

And such use-focused outreach opened up another space in which’ academic identity’ emerged as important, that is, the perceived credibility that non-academics associated with the ‘academic identity’. This became most apparent and relevant when academics crossed boundaries into contested and challenging non-academic settings. Although academics in my sample acknowledged the challenges of entering such spaces, my analysis revealed that these challenges were often alleviated by the ‘scientific capital’ and ‘credibility’ associated with an academic identity in terms of how these academics were perceived as having a legitimate and authoritative voice on an issue. Indeed, others have emphasised that more important than specific findings from an individual project in gaining the trust of users and stakeholders is the “credibility of an ongoing body of research that registered with users” (Meagher, Lyall, & Nutley, 2008, p. 170). Users, “therefore, are increasingly relying on trusted, credible, reputable sources with whom they have built relationships” (Bansal, Bertels, Ewart, MacConnachie, & O'Brien, 2012, p. 87).

Academic boundary-crossing and boundary management therefore involves transforming “scientific credibility” into “social capital” (McNie, 2007, pp. 20, 24; see also Ponomariov & Boardman, 2010, p. 617) – what Cordner (2015) calls “strategic science translation” (p. 916). This is about mobilising scientific capital to establish trust and credibility. What was interesting in many of the cases I studied was how this mobilisation seemed to be relatively unproblematic. This is not to say there were not challenges, but there was little evidence of the scientific capital and credibility of the researchers being significantly challenged by the non-academics they engaged with, even when the implications of their science were not entirely aligned with their interests. This finding agrees with Henkel’s (2004) argument that the notion of an ‘academic identity’ emerges as a powerful one governing not only the behaviours of academics, but also the way that academics are perceived by others when they “cross” (p. 179) academic boundaries into contested non-academic spaces, perhaps partly because users feel that links to academia can be a boost for their own professional credibility (Hoffman, 2011).

There is an interesting question about ‘academic identity’ in relation to disciplines. Generally, the issues of academic identity as discussed above emerged more frequently amongst Life scientists – in Chapter 4, illustrative case 2 (BoR5, ‘Sea Mammal Research & Impact’) and, to a lesser extent, illustrative case 3 (BoR4.2, ‘Informing MDMA Policy’), are both cases in point – but could be found across the whole spectrum of sciences. Some recent evidence and lines of argumentation highlight that disciplines are becoming relatively less dominant as the main factor shaping academia, and that more weight should be attached to the culture, mission and expectations of the particular university to which an academic belongs (Shields & Watermeyer, 2018; Trowler, 2014). Trowler (2014) has also moved away from a characterisation of disciplines as fixed “tribes” (p. 1722), belonging to which dictates all aspects of academic life. Informed by a more “nuanced” and “[c]ritical realist” approach, Trowler (2014) depicts academic disciplines as only partially and contingently causal, as relatively bounded but also relatively fluid “reservoirs of knowledge resources which, in dynamic combination with other structural phenomena, can condition behavioural practices, sets of discourses, ways of thinking, procedures, emotional responses and motivations” (pp. 1726, 1728, 1729). Therefore, drawing on the work of Bernstein, Trowler (2014) argues that, in addition to “Bernstein’s ‘discipline as research’ and ‘discipline as curriculum’, we can add other sites of practice within universities such as ... income generation” (p. 1274), and, I might add, impact-generation and boundary-crossing.

These more nuanced discussions of how disciplinarity may come to the fore in shaping academics’ experiences and sense of their place and identity sits well with my own analysis. My findings (see, for example, Table 37, p. 136) agree that institutional context may be more important than branch of science in terms of shaping academic boundary transactions and the levels of power and control over academic research, but that the research orientation (i.e. towards *use/applied research* or *understanding/basic research*) is perhaps as important. Indeed, the two main categorical dividing lines which my analysis revealed were between ‘elite’ and ‘non-elite’ (that is, the ‘more’ and ‘less’ prestigious categories) departmental contexts and between ‘applied’ and ‘basic’ research, with the latter including ‘use-inspired basic’ (which I categorised as Basic/Applied). Nuance is also required here, however, particularly in interpreting the apparent divide between applied and basic research. It would be an “analytical mistake” to equate applied academic research with a displacement of “academic value[s] and practice[s]” (Hoffman, 2011, p. 456), as if academic research has ever been solely focused on curiosity-based research and the dispassionate search for truth. Rather, applied research needs to be part of our understanding of academia – indeed, today, the majority of UK academics categorise their research as primarily ‘use-inspired’ research (Hughes et al., 2016).

With these nuances in mind, the most appropriate ways to summarise ‘academic identity’ as an explanatory theme vis-à-vis the reproduction of academic boundaries through research-related boundary transactions are as follows. First, ‘academic identity’ is a suitably powerful and loosely-defined concept such that heterogeneous academics can use their own sense of their academic identity as motivation to overcome internal and external challenges to achieve diverse boundary-transacting objectives, so that boundary transactions are a way for the enactment and realisation of their academic identities and goals. Second, many non-academic actors and stakeholders perceive ‘academic identity’ to be imbued with a credibility which they see as important to informing decisions in non-academic contexts.

‘Academic identity’ therefore fits the criteria of transcending the particular BoRs in my study. As such, although much has already been written on academic identity (I have not attempted to do justice to this literature) I argue that there is significant need for ongoing conceptual and empirical research on the diversity of meanings, applications and tensions associated with the notion of academic identity. The notion of academic identity remains complex and “overdetermined” (Kenny, Whittle, & Willmott, 2016, p. 149), interacting with multiple sources of power which provide agency but also limitations. The following section will focus on issues of power as a final explanatory theme and will touch on some of the more complex questions still surrounding academic identity, as well as experiences of academic boundaries and academia more generally, such as relating to power associated with different institutional and disciplinary contexts.

### Power and control over (academic) science

Bernstein’s (2000) notion of power focuses on “relations *between* [categories]. *…*Power relations ... create boundaries, legitimise boundaries, reproduce boundaries between different categories of groups, ... different categories of discourse, different categories of agents. ...” (p. 4-5, original emphasis). Maintenance of boundaries requires boundary transactions, which contribute to the wider societal legitimacy of the boundary. But boundary transactions open up the opportunity for a weakening of boundaries because there is a balancing act in that transactions must give enough so that wider societal legitimacy of the boundary is maintained, but not so much that the distinctiveness of the bounded category is lost. Thus, boundary transactions carry “both the power of reproduction and the potential for its change” (Bernstein, 2000, p. 5). A key issue in the reproduction of boundaries, that is, the reproduction of a distinctive bounded category with autonomy and authority over some domain of activity or discourse (i.e. an area of knowledge), is therefore whether the bounded category is able to maintain ‘control’ over its boundary transactions.

My empirical analysis suggests that the bodies of research studied do exhibit academic power and control over its boundaries and transactions. Accordingly, the explanatory themes presented in this chapter so far have aimed towards understanding how and why research-related academic boundary transactions tend towards the reproduction of academic boundaries: the educational function leading to academically-inclined non-academics with whom universities can transfer academic knowledge in relatively ‘low-cost’ ways; the academic trajectory which empowers academics to cast non-academic problems in academic terms, predominantly as an object of theoretical and disciplinary knowledge; the ‘academic identity’ bestowed upon researchers by virtue of their belonging to academia and the way this is perceived by non-academic actors.

But my analysis also suggests important limits and caveats which make this reproduction and maintenance of boundaries somewhat uncertain. There are two main elements of this which I present below as two sub-themes. The first relates to the uneven distribution of power within academia. The second relates to the uneven access to control and influence of boundary transactions afforded to external actors.

#### Internal: uneven distribution of power

Adopting a similar Bernsteinian ‘boundary’ lens to myself, Douglas suggests that where a group is sufficiently powerful and bounded, it may not be greatly “exposed to the need to communicate with outsiders” (Douglas, 1996, p. 55). In other words, more powerfully bounded categories or groups have greater power over their boundaries and more regulatory control over their boundary transactions. This means that more powerful universities at the top of the academic “hierarchy” will likely be better able to insulate themselves from “the *exigencies of the market*” (Bernstein, 2000, p. 60, original emphasis). Here, the difference between more and less ‘powerful’ institutions does not manifest in terms of the extent or frequency of boundary transactions – powerful universities will not tend towards an ‘ivory tower’ position – but rather in the control over the boundary transactions engaged with. What I mean by this is that more powerful institutions will be more able to resist pressures to engage in boundary transactions which disagree with their own sense of what is appropriate or valuable; they will tend to engage in boundary transactions which also allow them to advance their own academic agendas and which incur relatively few ‘costs’. For example, they may focus on those boundary transactions which can be accomplished by standard outputs such as journal articles and skilled graduates. By contrast, less powerful universities may engage in boundary transactions which pose greater challenges to their academic identity and values and/or which involve transmitting knowledge in new, more user-oriented ways. My analysis bears this out (see Table 37, p. 136): the research sampled from ‘elite’ departmental contexts was more ‘bounded’ than non-elite in those aspects of research most central to academia, i.e. the knowledge content and the centrality of academic credentials, whereas the research in non-elite departmental contexts had relatively less control over these aspects of research; this ‘boundedness’ in ‘elite’ departments’ research did not constrain the research to narrowly scientific objectives with little external relevance, but if anything led to the opposite, liberating the research in ‘elite’ departments to produce outputs which, although low in ‘transaction costs’ were readily relevant to and useable by external actors, while research sampled from non-elite contexts tended to be more reserved in terms of the extent to which research questions and outputs were oriented towards specific outcomes; and yet the outputs from ‘elite’ departments more typically took the form of standard academic outputs such as papers and technologies, while ‘non-elite’ departments more frequently produced or engaged in more user-friendly and high-cost transactions such as on-site development and application of research, and engaging directly with non-expert users, including members of the public.

On the dimension of institutional prestige, then, the analysis suggests that the uncertainties and tensions around boundary reproduction may be experienced predominantly by less prestigious institutions; ‘elite’ departments are able to exercise their power by engaging in boundary transactions which do not challenge their strong ownership and tight control over the knowledge content, but which allowed them to enact and reinforce their distinctive relation to knowledge, i.e. to the ‘transcendental’ (or the ‘sacred’) (Bernstein, 2000; Durkheim, 1915). But while this description has merit vis-à-vis a comparison between more and less powerful institutional contexts, it obscures other interplays of power and control which operate across all academic contexts and instil a more general precariousness.

#### External: multiple scientific systems

Academia may be the central knowledge institution in society, but it does not hold a monopoly over the production, conduct or direction of science (Brennan et al., 2016). When the sampled research was analysed from the perspective of research orientation, that is, orientation towards use-oriented/applied research or understanding-oriented/basic research, I interpreted variation in terms of the way that research in different categories aligned to different broad knowledge systems. The research from Basic disciplines frequently aligned, through technology research and development, to a ‘technoscientific’ system in which large industry and nation states are interested in the power afforded by new technologies which, just as they push back the frontiers of data-collection for scientific purposes, also drive the cutting edge in production for commerce and national security. Research from Applied disciplines often aligned to a ‘Mode 2’ system which challenges academia’s preferred mode of conducting science, with a transdisciplinary (as opposed to disciplinary) approach to research focused on pre-specified outcomes (as opposed to open-ended projects) of localised import (as opposed to general or even universal relevance). The way in which I want to develop this discussion here is to draw on these findings to note the ways in which academia is systematically exhibiting an “orientation ... towards ... external dependency” (Bernstein, 2000, p. 52). The point is that not only is there the theoretical necessity for some form of boundary transaction, a necessity to be somewhat accessible and concede some control to wider society (Bernstein, 2000; Moore, 2013); but that, empirically, academic research seems to consistently depend on allowing access to and conceding control to *certain* external groups. The technoscientific system primarily operates at the level of industry and governmental powers who shape academic science by investing in and occasionally collaborating in research with academics. The ‘mode 2’ knowledge production system may be shaped by a more broadly distributed base of private interests, but is nonetheless dependent on knowledge-intensive commerce, as well as governmental innovation policies.

For Moore (2013, p. 80), the importance of this issue, that of *which* external group/actorsget access to bounded categories, is a key sociological implication of Bernstein’s theory. According to my analysis it is best to think in terms of two coalitions of interest in controlling science, with the state (national governments) important to both. One coalition is that around science-based technologies as a source of global political and military power; the other coalition is that around science and science-based technologies as central to innovation and economic growth. Not only are governments central to both, but they also increasingly intervene in the governance architecture of the academic sector, for example through performance-based funding allocation systems such as the REF. This explanatory sub-theme therefore highlights that national governments’ own interests and constraints contribute to the nature and culture of the system in which academic research operates. Bernstein (2000) writes of a “culture ... facilitated by the activities of funding agencies, state and private” (p. 63), a culture which predominantly favours and acts selectively upon research that can be measured in terms of economic value or contributions to other policy priorities. The late Bernstein was writing specifically of the context of the RAE and would surely have had even greater conviction in his analysis in light of the addition of ‘impact’ in REF2014. These factors – global demands for powerful technologies (‘technoscience’), countless demands for localised knowledge expertise to solve specific problems (‘mode 2’), and governments’ demand that national institutions contribute to the governments’ own perceptions of ‘national interest’ – all constitute realities which shape academia and academic boundary transactions, and which transcend the experiences of my sampled research.

Etzkowitz and Viale (2010) have summarised the situation for academic boundaries as follows: “Bounded entities persist but the boundaries are permeable; with networks and collaborations giving organizations an outward as well as an inward focus. Networking and *taking advantage of complementarities supersedes ‘boundary work’, or defence of structures, as an organizational priority*” (p. 602, emphasis added). This account emphasises how external powers’ knowledge demands present opportunities for rather than threats to academia. As a judgement on the “paradox” of the “competing logics” of universities (Shields & Watermeyer, 2018, p. 12), Etzkowitz and Viale’s (2010) account reflects one possible perspective, namely that the result of the paradox is a kind of “stability” (Shields & Watermeyer, 2018, p. 12), in that “[b]y ceding some control of their work to external resource providers, faculty members ... [are able to] insulate themselves” (Rosinger et al., 2016, p. 45).

My own evidence does, to an extent, align with this view. But it also finds evidence that the reproduction of any such stability should be considered to be potentially precarious. There are external forces acting upon academic boundary transactions and exerting control upon them. These external forces transcend any given policy or government, and even any given economy or state.

True, my analysis suggests that currently, the effects of these external forces may be being mediated by differential distributions of power within academia, so that powerful institutions feel the effects less strongly; for as long as traditionally prestigious universities do maintain power and control over their boundaries, there may be a sense of relatively secure reproduction. But to the extent that such powerful institutions depend upon the presence of less powerful universities to receive the brunt of external forces, this may not be a sustainable strategy. I do not find sufficient evidence to close the question on the stability of this situation and the long-term shape and strength of academic boundaries.

## Chapter summary

The four explanatory themes all relate to, but take to a new theoretical level, aspects of the ‘explanatory analysis’ in the final section of the Analysis chapter (Chapter 4). In Chapter 4 it was necessary to emphasise certain explanatory features in relation to particular contexts. The present chapter is about applying the critical realist (Bhaskar, 1998) framework to elaborate the main explanatory features and to argue that they represent underpinning realities which are always *part* of the processes shaping academia’s research-related boundary transactions.

For example, the theme of the ‘educational function’ was found to be most important in explaining how Formal scientists were found to experience eased (less ‘costly’) transactions than Life and Natural scientists largely because Formal scientists’ non-academic collaborators often had doctoral degrees and retained significant academic inclinations and networks, which eased interactions. However, in this chapter I emphasised that this is a broader underpinning reality shaping academia’s research-related boundary transactions.

Similarly, ‘academic identity’ was found in Chapter 4 to be particularly pertinent in explanations of the experience of Life scientists, whose sense of academic identity was often an important source of motivation to overcome challenges associated with crossing boundaries into politically contested spaces. Moreover, the perception of ‘academic identity’ as a carrier of credibility held by non-academics emerged as an important factor in their relative success in crossing these difficult boundaries. Again, the point made in the present chapter is that these dynamics are relevant more broadly, albeit that they appeared to come to the fore more prominently in my sampled research from Life sciences.

The ‘academic trajectory’, whereby academia in part reproduces its boundaries by internalising real-world issues faced in society into objects of academic, disciplinary knowledge, was most obviously exhibited in my category of Basic/Applied disciplines. However, the tendency towards ‘use-inspired basic’ research (Stokes, 1997), both in my sampled research and in UK academic research more generally (Hughes et al., 2016), highlights that this is a general process through which boundary transactions serve to simultaneously establish external legitimacy of and reinforce the strength of, academic boundaries – and it is perhaps even the most effective mechanism for this process in recent times.

Lastly, the interplay of internal and external sources and forces of ‘power and control’ over academic boundaries and boundary transactions highlights the limits, caveats and ultimately the precariousness of these boundary-reproducing mechanisms. My analysis suggests that, currently, this precariousness most strongly affects less prestigious institutional contexts in a sector characterised by differentiation of power and prestige. But it is best understood as a feature which acts upon Western society’s relation to scientific knowledge generally, and therefore transcends any particular configuration of policy, economy, ideology (i.e. neoliberalism) and academic sector. This presents an element of precariousness to the whole academic enterprise and should not be ignored by universities just because they may feel that they are benefiting from the current configuration.

# Chapter 6. Conclusion

## Introduction

This chapter summarises the key findings and contributions of my research and highlights the implications for theory and policy, particularly in relation to my aim of bringing empirical evidence to bear on analytical and normative debates on the extent to which universities are and should be ‘weakening’ or ‘maintaining’ their ‘boundaries’. With this aim in mind, I formulated research questions which focused empirically on the context of UK academic STEMM research through the lens of the metaphor of academic ‘boundaries’, a construct inspired by the sociology of Basil Bernstein. The overarching question and sub-questions this study aimed to answer were:

*What is the balance of ‘power’ and ‘control’ over the organisation, activities and societal relations associated with ‘high-impact’ academic STEMM research in the REF2014 context?*

Sub-questions:

1. *What role do different institutional and epistemic contexts play in shaping the balance of ‘power’ and ‘control’ over academic STEMM research?*
2. *What are the main forms and functions of ‘boundary transactions’ associated with the sampled academic STEMM research?*
3. *What are the implications of the balance of ‘power’ and ‘control’ for academic boundaries in the context of the ‘impact agenda’?*

Theoretically, these questions are grounded in my Bernsteinian understanding and use of the metaphor of ‘boundaries’ as a lens to study universities’ organisation, activities and relations, alongside his interrelated concepts of ‘power’ and ‘control’. ‘Power’ is understood as an institution’s or group’s ability to self-define the boundaries within which it has established a distinctive and legitimate authority over some domain of discourse, knowledge, practice or activity, while ‘control’ can be understood in terms of levels of ownership over the forms that boundary transactions take (Bernstein, 2000). A ‘boundary’ is to be understood as a device for regulating relations and interactions between actors. Boundaries are productive as well as restrictive, in that they can be thought of as institutionalised solutions to social ‘problems’ – for example, the problem of how academic institutions maintain their status as distinct, identity-conferring, knowledge-based institutions in the context of the increasing (pressure towards) engagement with and guidance from external actors and objectives.

‘Boundaries’ reflect and aim to preserve ‘power’ (Bernstein, 2000). But neither boundaries, nor the power which they reflect and preserve, are automatically maintained or reproduced simply by virtue of existing power and boundaries. Rather, their renewal and reproduction are contingent and must take place through the operation of social mechanisms. One of the mechanisms through which they are reproduced is via ‘boundary transactions’, whereby something is *given* between the bounded entity and wider society (or at least certain sections of it) such that the ongoing ‘boundedness’ is legitimised. What makes the focus on boundary transactions so timely and relevant for this study is that, as well as being mechanisms through which boundaries are regulated and reproduced, they are simultaneously mechanisms through which boundaries are crossed and potentially weakened. The ‘impact agenda’ can be understood as a policy aimed at increasing the intensity and frequency of academia’s boundary transactions. This raises the issue of whether the balance of these transactions tends towards the maintenance and reproduction of academic boundaries, or instead towards their re-shaping or even weakening. I have tried to operationalise this issue in my research questions, where ‘control’ refers to control over boundary transactions; the more that academia is able to maintain ‘control’ over its transactions, the more likely it is that these transactions will contribute towards the reproduction of academic boundaries rather than their potential weakening (see further theoretical discussion in Chapter 2).

Empirically, I approached the research by focusing on boundary transactions associated with n=19 bodies of research (BoRs) based at ten STEMM departments across nine UK universities. These BoRs and departments were purposefully sampled to focus my study on STEMM research covering a range of disciplinary and institutional contexts, but which had all been recognised for their ‘impact’ in REF2014. I wanted to identify research recognised for having significant impact because it seemed reasonable to assume that research which achieved significant ‘impact’ would likely have involved many ‘boundary transactions’ of different forms and at different times, and it was important to my research questions that I capture the functioning of a range of boundary transactions in their actual research contexts. Another reason for focusing on research recognised for its impact was to seek to understand more about the kinds of research and related activities which are privileged and valued in the current system. My main data sources were documentary materials, including: information about the research and the department submitted to REF2014; outputs from the underpinning research; other information about the research such as grant proposals or press releases; and web pages about the research, the individual researchers or research units involved, as well as web pages related to any non-academic actors involved in the research (for example who were mentioned as playing an important role in the REF2014 documents, or who were acknowledged in academic outputs as collaborating or otherwise supporting the research, or who interview respondents mentioned as being important). In total I gathered 345 documentary materials for analysis. In addition, I conducted 10 interviews with key individuals involved in the sampled research.

I argue that the consistency of the narrative that can be derived from the documentary and the interview data and of the qualitative and quantitative analyses, indicate a robustness in my conclusions, and justify some ‘analytical’ or ‘theoretical’ generalisability. However, this design, like all research designs, also introduces limitations to the kinds of generalisations and wider implications I can infer from the findings. I am unable to make generalisations in terms of the statistical representativeness of my sample. A different sample, even which followed the same sampling criteria, might have yielded different results. More specifically, my sample led me to focus on highly successful BoRs and academics, and a quite narrow demographic of participants, and a sample which prioritised a broader range of academic seniority and demographic characteristics may have led to different findings. Indeed, for many researchers in more precarious situations and on fixed-term contracts doing prespecified research under an established academic, their role in and relation to the process of producing and disseminating knowledge may be vastly different to most of my respondents, and it may be that the majority of today’s ‘early career researchers’ never obtain the space to develop the kinds of networks and relationships that underpin the research and impacts that I have studied in my sample – and the rewards now associated with impact may well exacerbate pre-existing inequalities (Kellard & Śliwa, 2016).

The other main source of limitation is the decision to focus on STEMM fields. As was my intention, this decision allowed me to generate more specific and detailed insights into the mechanisms through which academic boundaries are crossed, maintained and regulated, and how these mechanisms are shaped, influenced and mediated by nuanced differences in epistemic content and context. However, it makes it difficult to draw out the relevance of my findings for the arts, humanities and social sciences (AHSS). I argue that the core concepts of academic boundaries and boundary transactions, and the underpinning interplays of power and control, have relevance to academia in general, but one of my arguments and findings is that the specific epistemic context is a factor in shaping how these play out, so that it would require further empirical research to explore boundary transactions in different AHSS disciplines. Therefore, although I would be cautious in drawing inferences for AHSS, my study would lead me to expect that a discipline such as economics, which is largely application-oriented and underpinned by ‘formal’ knowledge content (i.e. mathematics) might exhibit similar forms of and control over its boundary transactions as those exhibited by the engineering disciplines in my study. For example, one can perhaps imagine that economics departments largely interact (transact) with the kinds of non-academic organisations which are likely destinations for graduates of such departments (e.g. companies, think tanks, civil servants), leading to similar boundary transactions and transaction costs as was the case with several of the engineering departments (and Formal science departments more generally) in my study. For another example, a key distinguishing characteristic curiosity-inspired Basic disciplines in my sample was the way in which they became interlinked with powerful governmental and industry actors with stakes and resources to mobilise science and technology towards a range of national interests. One may conjecture a parallel between here with a more understanding-focused, curiosity-inspired AHSS discipline such as history, whereby academic historians and national and international actors share an interest in shaping historical narratives of relevance to political debates.

Clearly, it would take detailed empirical analysis of specific bodies of AHSS research to tease out the key interplays of power and control and the role of boundary transactions, and this is a task for future research. In the remainder of this chapter, I will conclude the thesis by drawing upon the full range of findings and insights to discuss the implications of the research for academic boundaries and for those who have a stake in them, particularly academics themselves, notwithstanding the limitations I have discussed.

## Findings

In response to the overarching question about the balance of ‘power’ and ‘control’ over the organisation, activities and societal relations associated with the sampled STEMM research, I find evidence that this predominantly lies within academia. The analysis highlights the significant power that academic institutions continue to hold over the boundaries of who counts as legitimate producers of academic knowledge, with the doctoral degree continuing to be the key qualification for induction into a class of stewards over academic knowledge. In this sense, what gets to count as ‘academic knowledge’ is, to a large extent, simply that which attracts the interest of sufficiently academically qualified individuals who work within, or in collaboration with, academic institutions. The study also serves as a reminder of the predominance of traditional forms of communicating research knowledge via academic journals, patents, technical reports and technical guidelines targeted at the scientific community – albeit that the ‘scientific community’ does sometimes extend beyond those employed by universities to include non-academics, but normally only those that hold doctorates and have close continuing links to academia.

However, analysis also revealed significant tensions in the power and control over academic boundaries and boundary transactions, emphasising that the reproduction of academic boundaries should be considered inherently contested and contingent rather than guaranteed. I shall highlight these tensions in the following two sections.

### Tensions in boundary reproduction: Non-academic sources of power and control of over science

Academic research frequently links to and depends upon systems which are largely beyond its control, such as the wider ‘technoscientific’ system (Leydesdorff, 2012). Although technological innovations developed in an academic context are driven, from the academic’s point of view, by the goal to attain new powers of observation, data-collection and analysis than previously possible, the support and legitimation essential for resourcing such research derives primarily not from the scientific objectives per se, but because the resultant technologies are valuable to broader attempts, amongst various political, military, industrial, civil and social networks (Latour, 1987) to “control” (Bensaude-Vincent et al., 2011, p. 366) and “construct” (Schmidt, 2011, p. 104) the world in which we (desire) to live. This situation describes well many of the BoRs in my research sampled from Basic disciplines (mathematics, biology, chemistry and physics), where these external sources of ‘power’ and ‘control’ over science became manifest in the relatively high levels of ‘boundary spanning’ scientists associated with these BoRs who had significant expertise and experience in both academia and industry (see discussion around Figure 16).

Also largely beyond academic control is the system of ‘mode 2’ knowledge production (Gibbons et al., 1994). It is now more than two decades since the prevalence of ‘mode 2’ research started provoking concerns of a post-academic science (Ziman, 1996). Regardless of one’s view on this assessment, ‘mode 2’ forms of knowledge production – “transdisciplinary and ... organized around problems that are defined by the context of use” (McNie et al., 2016, p. 888) – pose significant challenges to academia’s perceived ‘natural’ or preferred mode, governed by rules derived internally from academia, anchored primarily in disciplinary communities and driven to advance the reach and generalisability of disciplinary theory. They also challenge the criteria for reliable and prestigious knowledge. Under mode 2, it is no longer sufficient that epistemologies be scientifically “reliable...; knowledge also needs to be ‘socially robust’, because its validity is no longer determined solely, or predominantly, by narrowly circumscribed scientific communities, but by much wider communities of engagement comprising knowledge producers, disseminators, traders, and users” (Nowotny et al., 2003, pp. 191-192). Indeed, the BoRs I sampled from Applied disciplines (e.g. engineering, materials science and medicine) displayed significant, sometimes even quite extreme ‘mode 2’ characteristics, in terms of prioritising the use and impact of research over the theoretical relevance or depth of understanding achieved by research. In many of these BoRs, scientific expertise and effort was co-ordinated around the integrating principle of collaborating to find transdisciplinary solutions to localised social, economic and technological problems, rather than around the integrating principle of advancing disciplinary knowledge.

These insights highlight that academia, although arguably the core institution of science, does not hold a monopoly over science. Rather, there are significant *non-academic sources of ‘power’ and ‘control’ over the scientific system*, and there are significant interdependencies, interactions and flows of influence between the objectives, interests and activities of academic and non-academic scientific institutions and stakeholders.

### Tensions in boundary reproduction: Variation and imbalance in internal sources of power

Another source of tension derives from the variations in the experience of academic research across dimensions of disciplinary and institutional context. For example, BoRs from what I referred to as ‘elite’ departments (those which achieved a high Overall rating in REF2014 *and* which are based in ‘prestigious’ universities, as defined in Chapter 3) often exhibited different kinds of boundary transactions than those from ‘non-elite’ (comprising the categories of ‘more’ and ‘less’ prestigious) departments. The focus in ‘elite’ contexts was often on boundary transactions which took the form of ‘use-oriented outputs’ (‘boundary objects’) which had immediate applicability for users, and they tended to exhibit fewer examples of the more interpersonal forms of boundary transaction such as ‘outreach’ and ‘collaboration’ (in the form of co-authorship). Similarly, there was also variation by branch of science. For example, Formal scientists (i.e., mathematically-based disciplines such as informatics and much engineering) typically faced far fewer boundary challenges because they almost exclusively transact with external actors who have PhDs and have maintained significant links with academia and, arguably, retained something of an ‘academic identity’, therefore greatly easing transactions. By contrast, Life scientists (e.g. biology and medicine) faced greater boundary transaction challenges as they interacted with a broader range of actors, most of whom do not have a shared academic background or shared understanding of scientific issues.

From one perspective, the main lesson from analysis of such variations is that they can best be understood as different manifestations of similar underpinning structures and forces. That is, as I have argued, there is a tension inherent in the distinct ‘identity’ of the bounded or ‘insulated’ university (Bernstein, 2000) and this is simply part of an ongoing and necessary interplay between the academia’s pursuit for both autonomy and legitimacy (B. R. Clark, 1985, 1987), which plays out differently in different contexts. However, the variations are not neutral but reveal an internal source of tension in the reproduction of boundaries. This is most apparent in the observed variation between different institutional contexts in terms of prestige and reputation. ‘Elite’ institutional contexts were found to be associated with a greater ability to resist pressures to engage in boundary transactions which disagree with their own sense of what is appropriate, valued or worthwhile, exhibiting significant ‘power’ and ‘control’. By contrast, ‘non-elite’ universities were found to engage in boundary transactions which pose greater challenges to their academic identity and values and/or which involve transmitting knowledge in new, more user-oriented ways, exhibiting less control over boundary transactions. This suggests that the effects of external forces challenging academic boundaries may be being mediated by differential distributions of power within academia, so that ‘elite’ institutions feel the effects less strongly. The reproduction of boundaries therefore appears more uncertain from the perspective of less powerful institutions.

However, as has been highlighted throughout the analysis and earlier in the present chapter, boundary challenges are faced by all institutions, however prestigious and powerful[[26]](#footnote-26). It is on the basis of there being a general challenge to academia that I will proceed with discussion of the wider implications of the study in the final section of this chapter. First though, I will discuss some of the theoretical implications of my analysis, focusing on mechanisms and underpinning structures which help to explain my findings.

### Boundary mechanisms and underpinning structures

A literature review pointed me towards five main forms of boundary transaction, and I found these suitable to capture and classify the boundary transactions identified in my sample of research. These included ‘outreach’, ‘collaboration’, ‘use-focused output’, ‘boundary structures’ and ‘boundary-spanners’ (Chau et al., 2017; W.C. Clark et al., 2011; Hoffman, 2011; Vakkuri, 2004). Analysis revealed a nuanced and complex role for boundary transactions. As well as involving a crossing, loosening and opening up of boundaries (Henkel, 2004), I found that they often also served to sustain and potentially reproduce academic boundaries. Indeed, the boundary transactions associated with my sampled BoRs were found to tend more towards the reproduction of boundaries than their weakening.

For example, although ‘transdisciplinary structures’ (a form of ‘boundary structure’) are problem-focused and normally somewhat separated from traditional disciplinary departments, they often fulfilled their boundary transaction function largely by conducting academic research in a more or less traditional way. Moreover, research collaborations with non-academic organisations might be expected to occur mostly when the research was ‘close to market’ or application, with little need for underpinning research; however, my analysis found that collaborative research often occurred at the early stages of research, suggesting that such boundary transactions are not merely about instrumental transactions to score a ‘quick’ impact. Rather, they indicate that non-academic scientists often provide academic scientists with the precise ingredients, such as long-term intellectual problems, data, expertise and funding, that are essential to academia reproducing its position as both a distinct, and distinctly valuable, knowledge institution. Boundary transactions also often contributed not only to an ‘impact agenda’, but also contributed to ongoing academic research. For example, the same ‘use-oriented’ outputs that were delivered to non-academic contexts of application often were also used in ongoing academic research. Similarly, ‘outreach’ activities often served not only the ‘third’ mission that has come to be associated with outreach and engagement, but also directly contributed to one or both of universities’ traditional missions of research and teaching.

In short, boundary transactions were found to involve not only crossing academic boundaries and advancing the interests and objectives of those beyond these boundaries, but also, and simultaneously, they furnished universities with various inputs and ‘capitals’ which are essential to the maintenance and reproduction of academic boundaries. Addressing externally generated objectives and interests is not therefore necessarily incompatible with advancing academic objectives and interests; crossing academic boundaries does not necessarily imply weakening academic boundaries. Indeed, taking control over boundary transactions is key to reproduction of boundaries, as boundary transactions can serve to display academia’s distinctive value whilst enacting its distinctive identity, trajectory and mode of operation (Bernstein, 2000).

From the critical realist metatheoretical framework adopted, this was conceptualised as a surface-level finding that warranted further explanation. I posited certain underpinning structures and mechanisms that transcend the specific contexts and strategies associated with the specific sample of research studied, and which can be said to act upon universities and their research-related roles, activities and interactions with wider society. The first of these was the educational function of universities. Graduates, especially doctoral graduates, who bring their advanced academic training and skills into non-academic knowledge-intensive sectors, constitute, in my framework, a form of boundary transaction (I classify this under the ‘boundary-spanner’ category). All forms and instances of boundary transaction potentially operate more towards reproducing *or* weakening academic boundaries. For example, although, by bringing valued academically-derived skills and training into a non-academic workplace, graduates are contributing to legitimacy of universities’ function as knowledge-transmitting institutions, it may also be possible that advanced training of students is so geared towards specific sectors or companies that the balance of control over this transaction shifts away from the academic institution. However, the long-term effect of increasing numbers of academically trained graduates entering non-academic workplaces constitutes an underpinning reality shaping the context for all future interactions and transactions between academia and other knowledge-intensive sectors. An appropriate metaphor might be the *extension* of academia’s boundaries into these other sectors, as (doctoral) graduates bring their academic skills, approaches, contacts and inclinations into non-academic contexts of application. In this perspective, academia is creating opportunities for itself to develop, expand, generate new sources of research revenue and scientifically challenging problems, and at the same time ensuring that relevant contexts of application are populated by like-minded individuals and have the ‘absorptive capacity’ (Bishop et al., 2011) to be able to demand, apply, and occasionally collaborate on academic research. This results in conditions which are conducive to enabling academia to engage in boundary transactions.

Second, I highlighted academia’s central internal trajectory, or what Durkheim (2013) calls the university’s “*sui generis* … identity” and “ideal … destiny”, that is, to incorporate in its domain “a plurality or even the totality of the branches of human learning” (p. 93, original emphasis). Because of this trajectory, academia is constantly open to novel ways of *objectifying* the world, that is, of making ever more finely classified natural phenomena objects of academic knowledge. This trajectory links up with and finds synergies with ‘challenges’ facing humanity, for example around issues of health, the environment and technology. When new inter/multidisciplinary sub-fields which aim to advance fundamental understanding of issues which are of inherent relevance to certain groups, such as fields of marine mammalogy, psychopharmacology, conservation ecology, or systems engineering (to take some examples from my own sampled research), coalesce into dedicated research units or centres or departments, these can be understood as forms of boundary transaction (which I have called ‘boundary structures’) in that they are statements of academia’s commitment to contributing to non-academic issues. But it is simultaneously a mechanism through which academia is enacting its inherent trajectory. The internalising of non-academic issues into academic structures therefore is an important mechanism for the reproduction of academic boundaries.

Third, I argued that there is a sense in which the notion of an ‘academic identity’, which transcends any particular definition of this term, constitutes an underpinning reality contributing to the reproduction of academic boundaries – indeed, the ambiguity and open-endedness of the concept is part of its strength. There were two main strands to my argument regarding academic identity. First, ‘academic identity’ emerged as a powerful but loosely-defined concept such that heterogeneous academics can use their own sense of their academic identity as motivation to overcome internal and external challenges to achieve diverse boundary-transacting objectives, so that boundary transactions are a way for the enactment and realisation of their academic identities and goals. Second, many non-academic actors and stakeholders perceive ‘academic identity’ to be imbued with a credibility which they see as important to informing decisions in non-academic contexts. This meant that key actors in non-academic contexts, who were recipients of or partners in academia’s boundary transactions, were generally ready to accept academic input, if not to actively seek it out. Although beyond the empirical scope of my research, academia’s values of autonomy, criticality and objectivity are presumably key to this external perception, and this perception in turn is conducive to enabling boundary transactions.

Lastly, and as discussed earlier in the chapter as one of the key tensions identified, was the fact that academia, although arguably the core institution of science, does not hold a monopoly over science. Rather, there are significant *non-academic sources of ‘power’ and ‘control’ over the scientific system*, and there are significant interdependencies, interactions and flows of influence between the objectives, interests and activities of academic and non-academic scientific institutions and stakeholders, such as governments, military and industrial actors.

## Implications

### Here to stay? The necessity of boundary transactions and *some form* of ‘impact agenda’

In the Introduction, I wrote that my research would inform not only analytical debates about the extent to which non-academic objectives *are* influencing academic research and reshaping or weakening academic boundaries, but also normative debates about the extent to which this *should* occur. My findings imply that those concerned about academic boundaries and the pressures that academic institutions and researchers are under to cross, reshape and potentially weaken them, must also acknowledge that boundary transactions also often function to reproduce academic boundaries and to furnish universities with the resources to achieve this. Moreover, the impact agenda is a manifestation of necessary tensions or paradoxes associated with the academic enterprise. Structures and processes such as academic-industry partnerships, transdisciplinary or problem-centred research centres, outreach missions, knowledge transfer offices, etc., are manifestations of *necessary* boundary tensions. From this perspective, the immediate policy context of the ‘impact agenda’ is largely a construct or a symptom of broader interplays of power and control, in which the university will always be only *relatively* autonomous and bounded, such that the university must necessarily share power and control (albeit not necessarily evenly) over the strength and shape of its boundaries, and the direction and nature of its activities, with other stakeholders (perhaps inevitably with the State, predominantly). This analysis suggests that boundary transactions, and even some form of ‘impact agenda’, are here to stay.

Having said that, my study acknowledges that the precise manifestation of these necessary tensions is conditioned by both local contexts (i.e. of specific disciplines and departments) and by broader interplays of power and control over (academic) science. The specific context of the ‘impact agenda’ and the way it is taken up by the academic sector can be understood as a particular manifestation of a distinct configuration of micro- and macro-level contexts interacting selectively on the academic sector. Therefore, while on the one hand my analysis has some restrictive implications for current debates – namely, that it is unrealistic and probably self-defeating to seek to halt academia’s boundary transactions with wider society and to imagine a time where there is no form of ‘impact agenda’ – it also provides a grounding for ongoing and imaginative debate about what forms these should take. That is, the current manifestation and institutionalisation of ‘impact’ should be interrogated, critiqued and, I would argue, resisted.

### Challenging the impact agenda: mismanagement and ‘misrecognition’

The UK ‘impact agenda’, institutionalised mainly in REF2014, is neither the only nor the optimal manifestation of the necessity of academia’s boundary transactions with wider society. The excessive pressure associated with the UK impact agenda came through at a personal level in my research through participant interviews. Although most participants felt passionately about having an impact on society through their research, and despite having benefited from success in the impact element of REF2014, most talked about REF impact critically. They saw it as placing unnecessary administrative burdens on universities and their staff and inappropriate expectations upon many fields of research to generate relatively narrowly and instrumentally defined ‘impact’ data. Most participants felt that their own topics of research and approaches to engaging potential collaborators and users ‘just so happened’ to coincide with what was valued in REF2014, but none, when asked, felt that this was something that all researchers and research fields should be expected to aim for or be evaluated on. To a large extent, these issues can be thought of as mismanagement in terms of the pressures that universities place on their own researchers to address the impact agenda in narrowly defined ways.

More fundamentally, the whole approach to the assessment of impact as institutionalised in the REF appears to be, at least in part, a case of ‘misrecognition’ (Bernstein, 2000, p. 53). Misrecognition is where actions or decisions, including policy decisions, are predicated upon a solely “functional analysis of what is taken to be the underlying features necessary” to “perform” (Bernstein, 2000, p. 53) or achieve a certain task or objective, such that the decision making process fails to recognise and take account of the complex sociocultural context underpinning a given outcome. The impact agenda, as currently institutionalised, attempts to steer researchers to ‘perform’ impact effectively. The ‘misrecognition’ takes the form of an assumption, which is implied within much policy and discourse across the academic sector (even if it is not fully held and endorsed by specific individuals), that research can achieve or ‘perform’ impact simply by complying with so-called ‘best practice’ or with the values espoused by the REF and wider policy discourse. These assumptions risk failing to understand (to ‘recognise’) the contextual specificity underpinning ‘impact’, which is comprised of complex institutional, epistemic and sociocultural elements, as well as idiosyncratic personal and interpersonal elements, in which a given set of boundary transactions came to be seen as an appropriate, legitimate, authentic and worthwhile way forward for those involved. One of the main reasons for my qualitative approach and relatively small sample was to capture some of these contextual elements, and to show that boundary transactions must be *recognised* as part of the necessary tension of the academic endeavour, and that they can therefore occasionally be productive tensions. This is as opposed to the alternative possibility, that boundary transactions be *misrecognised* as merely a way to ‘perform’ impact. An appropriate recognition of boundary transactions can result in their contributing constructively to the academic endeavour, to academic identities and academic boundaries.

### ‘Entrepreneurial’? ‘Ecological’? Towards a “boundary-creating self-conception for the university”

B.R. Clark’s (1998) proposed twenty-first century solution to instilling an appropriate recognition of and approach to boundary transactions was the ‘entrepreneurial university’. This would institute “a state of continuous change” in order to respond and “adapt effectively to a changing society” (B. R. Clark, 2004, p. 357). B. R. Clark (2004) pointed optimistically forward to the prevalence of a type of university inspired by competition and moved by revenue-generation but simultaneously comfortable with “cross-subsidizing ... ‘useless’ things” which contribute to “cultivation and transmission of a cultural heritage as well as to economic progress” (p. 358).

Barnett (2017), with the benefit of nearly two decades’ experience of the challenges facing universities in the twenty-first century, and adopting a more combative mode of “fend[ing] for” (Barnett, 2017, p. 157)rather than merely “offer[ing] a brief for” (Clark, 2004, p. 17) the twenty-first century university, aims to instil a greater sense of morality and ‘[u]rgency’ by demanding what he calls an ‘ecological university’ (Barnett, 2017, p. 1). In this conception, academia’s “self-reproduction” and “self-interest” must be grounded on a “reciprocity” between universities and wider society (Barnett, 2017, pp. 47, 145).

The “idea of the ecological university can be seen as a contender with that of the entrepreneurial university” in that, in addition to acknowledging the need to contribute to wider society, it is also “grounded in a sense of the large forces that are destabilizing the university and steering it in certain pernicious directions” (Barnett, 2017, p. 171). It is therefore underpinned by a “Bhaskarian” (e.g. Bhaskar, 2000, 2008; Barnett, 2017, p. 85) sense of “the deep ‘generative mechanisms’ ... that underlie the dominant institutions ... which hold the forces of power” (Barnett, 2017, p. 159). These are the kind of underpinning ‘mechanisms’ and structures which I have sought to uncover in my study; they are those which shape the distribution of power within academia as well as those which shape the context and direction of academia from the outside. From this perspective, governmental policies and academic leadership are important forces of power, but they are also themselves symptomatic of broader forces such as those associated with ‘technoscience’ and ‘mode 2’, which transcend any specific government, policy, economy or academic sector, institution or actor.

My underpinning philosophy, theoretical framework, and my findings, therefore share much in common with Barnett’s (2017) vision. Another thing it shares is “a measure of optimism” (Barnett, 2017, p. 171). That the most immediate challenges facing universities and academics, that is, those associated with institutional management and national policies, are seen as *surface-level* forces, highlights that they can and should be challenged and, if necessary, resisted on grounds of protecting the long-term reproduction of academia as a distinct and distinctly valuable institution. In particular, the impact agenda can be criticised precisely because the notion of ‘impact’ ignores the “reciprocity” (Barnett, 2017, p. 145) essential to effective, authentic, and sustainable boundary transactions:

“Impact has no time for reciprocity. ... It conjures an *instrumental* form of engagement ... [with] no sense of entanglement, of two entities being to some degree entwined with each other... Quite the reverse: this is a connectivity that is devoid of a relationship. ... It is evident that the language of impact has to be not merely abandoned, but sharply repudiated” (Barnett, 2017, pp. 144-145, original emphasis).

While my analysis may be less virulent towards ‘impact’ and the ‘impact agenda’ than Barnett’s, his normative vision is helpful in articulating empowering implications from my research. The main implications along these lines are: the need for academic institutions and those employed by them to acknowledge that there are tensions and uncertainties to the reproduction of academia as a central and autonomous knowledge institution; to reflect on and strive for a “boundary-creating self-conception for the university” (Considine, 2006, p. 269) which empowers them to take ownership over boundary transactions; and to be willing “to engage in boundary work aimed at demarcating the proper scope of university pursuits” (Nickolai et al., 2012, p. 206). The point is not to come to a unanimous or final ‘self-conception’ or notion of the university’s ‘proper scope’, but to take responsibility for reflecting on and working towards these values, however defined, individually and collectively. The alternative is that national policies and institutional management priorities which misalign with these values will be free to “reshape ... university boundaries” narrowly and instrumentally, as a mechanism to “repurpose universities as drivers of a global knowledge economy” (Wright, 2016, pp. 61, 71) without due regard for their long-term integrity, reproduction and potential for producing and sharing world-changing ideas and innovations.

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# Appendices

## Appendix A. Definitions of REF starred ratings

|  |  |
| --- | --- |
| 4\* | Impact: Outstanding impacts in terms of their reach and significance.  Environment: An environment that is conducive to producing research of world-leading quality, in terms of its vitality and sustainability.  Output & Overall: Quality that is world-leading in terms of originality, significance and rigour. |
| 3\* | Impact: Very considerable impacts in terms of their reach and significance. Environment: An environment that is conducive to producing research of internationally excellent quality, in terms of its vitality and sustainability.  Output & Overall: Quality that is internationally excellent in terms of originality, significance and rigour but which falls short of the highest standards of excellence. |
| 2\* | Impact: Considerable impacts in terms of their reach and significance.  Environment: An environment that is conducive to producing research of internationally recognised quality, in terms of its vitality and sustainability.  Output & Overall: Quality that is recognised internationally in terms of originality, significance and rigour. |
| 1\* | Impact: Recognised but modest impacts in terms of their reach and significance.  Environment: An environment that is conducive to producing research of nationally recognised quality, in terms of its vitality and sustainability.  Output & Overall: Quality that is recognised nationally in terms of originality, significance and rigour. |
| Unclassified | Impact: The impact is of little or no reach and significance; or the impact was not eligible; or the impact was not underpinned by excellent research produced by the submitted unit.  Environment: An environment that is not conducive to producing research of nationally recognised quality.  Output & Overall: Quality that falls below the standard of nationally recognised work. Or work which does not meet the published definition of research for the purposes of this assessment. |

## Appendix B. Methodological details

### Appendix B.1. Sampling

#### Additional details on selecting Case Studies and underpinning Bodies of Research (BoRs) from sampled departments

Table 38 shows the total number of Case Studies in each submission, the total number of sampled case studies, and finally the total number of distinct bodies of research. That is, some of the Case Studies from a given submission are based on closely related bodies of research which, for the purpose of my analysis, I treat as united so as not to duplicate analysis of the same body of research. In effect then, although the Case Studies represent my main source and ‘way in’ to the data, my unit of analysis is better understood to be the underpinning body of research (BoR).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **REF2014 UoA** | **Institution** | **Total Case Studies** | **Sampled Case Studies** | **Distinct bodies of research underpinning the ‘sampled case studies’** |
| 1 | University of Glasgow | 19 | 5 | 2 |
| 4 | University of East London | 2 | 2 | 2 |
| 5 | University of St Andrews | 6 | 4 | 1 |
| 7 | Edinburgh Napier University | 2 | 2 | 2 |
| 8 | Queen's University Belfast | 4 | 3 | 3 |
| 9 | Cardiff University | 3 | 2 | 1 |
| 10 | University of Glasgow | 5 | 2 | 2 |
| 11 | University of Portsmouth | 2 | 2 | 2 |
| 13 | University of Cambridge | 4 | 2 | 2 |
| 14 | University of Sheffield | 4 | 2 | 2 |
| **Total** | | **51** | **26** | **19** |

Table 38. Total Case Studies and Sampled Case Studies from the ten submissions

My sample of Case Studies incorporates just over half of all the selected submissions Impact Case Studies (26/51 Case Studies). Table 39 shows that my sample comes very close to achieving a minimum of half of all Case Studies associated with each of the different dimensions’ categories. Of twelve categories, eight are represented above a level of 50%, with the lowest being 38%. All four instances of representation lower than 50% are due to the inclusion in that category of Glasgow’s very large UoA1 submission, which somewhat skews the percentage of sampled Case Studies from this submission downwards. Overall, I believe that my sampling strategy captures a sufficient proportion of all parameters to allow me to make reasonable inferences about the range of boundary processes associated with each of them.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameters and Categories (no. of submissions)** | **Total Case Studies** | **Sampled**  **Case Studies** | **% of Case Studies sampled** | **Distinct bodies of research** |
| **Tier** |  |  |  |  |
| Tier 1 (1) | 4 | 2 | 50% | 2 |
| Tier 2 (6) | 41 | 18 | 44% | 12 |
| Tier 3 (2) | 4 | 4 | 100% | 4 |
| Tier 4 (1) | 2 | 2 | 100% | 2 |
| **Aim/Orientation** |  |  |  |  |
| Basic (4) | 22 | 15 | 68% | 11 |
| Applied (4) | 33 | 14 | 42% | 12 |
| **Branch of science** |  |  |  |  |
| Life (3) | 29 | 12 | 41% | 5 |
| Natural (2) | 13 | 9 | 69% | 4 |
| Formal (3) | 15 | 8 | 53% | 8 |
| **Departmental rating** |  |  |  |  |
| High (3) | 11 | 6 | 55% | 5 |
| Medium (4) | 34 | 13 | 38% | 8 |
| Low (3) | 6 | 6 | 100% | 6 |

Table 39. Relative representation (%) of each parameter/category in sampled Case Studies

#### Additional details on recruiting interview participants

As noted, I also contacted key researchers from each of the selected Case Studies for interview. I was able to arrange and conduct interviews with ten respondents out of thirty-nine invitations sent (see Limitations section for a detailed discussion of response rates). Each of my ten interview respondents had been key researchers in at least one of the Impact Case Studies of their institution’s submission, and in some cases more than one. In total, my ten respondents were involved in nineteen of the twenty-six Case Studies in the sample and fourteen of the nineteen BoRs. Table 40 shows the proportion of Case Studies in each of the categories whose researchers were interviewed. Although there were inevitably some categories with less representation than others, no category went unrepresented in the sample of interview respondents.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameters and Categories  (no. of submissions)** | **Total Cases** | **Sampled**  **Case Studies** | **Cases with interviewee involvement** | **Proportion of Cases with interviewee involvement** |
| **Tier** |  |  |  |  |
| Tier 1 (1) | 4 | 2 | 1 | 25% |
| Tier 2 (6) | 41 | 17/18 | 13 | 32% |
| Tier 3 (2) | 4 | 4 | 3 | 75% |
| Tier 4 (1) | 2 | 2 | 2 | 100% |
| **Aim/Orientation** |  |  |  |  |
| Basic (4) | 22 | 15/16 | 11 | 50% |
| Applied (4) | 33 | 14 | 12 | 36% |
| **Branch of science** |  |  |  |  |
| Life (3) | 29 | 12 | 13 | 45% |
| Natural (2) | 13 | 9 | 5 | 38% |
| Formal (3) | 15 | 8/9 | 4 | 27% |
| **Departmental rating** |  |  |  |  |
| High (3) | 11 | 6 | 4 | 36% |
| Medium (4) | 34 | 13/14 | 10 | 29% |
| Low (3) | 6 | 6 | 5 | 83% |

Table 40. Relative representation (%) of each parameter/category among sampled interviewees

### Appendix B.2. Letter to potential interview participants

Mr. Eliel Cohen

The School of Education

The University of Sheffield

241 Glossop Road

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S10 2GW

[ECOHEN1@SHEFFIELD.AC.UK](mailto:ECOHEN1@SHEFFIELD.AC.UK)

[Date]

Dear [Participant name]

This is an invitation to participate in an interview for my study conducted as part of a Faculty-funded doctorate at the University of Sheffield, School of Education. I have contacted you because your work and experience are of special relevance to my research.

I research the ways that universities engage with wider society. The aim is not to measure or evaluate such activities, but rather to better understand the organisational structures and collaborative arrangements which underpin them.

In order to identify examples of universities interacting with wider society, I have drawn on a selection of submissions to the Impact element of the Research Excellence Framework 2014. One of the submissions included in my study is [Institution Name]’s submission to [Unit of Assessment No.] ([Unit of Assessment Name]) – this is how I have come across your work. I have already conducted desk-based research (described in the Information Sheet, enclosed) of these Impact submissions and their underpinning research. I now hope to conduct interviews with key researchers (one researcher per selected Impact Case Study).

The proposed interview will focus on your work on [detail of research], as well as touch on some more general issues related to your experiences as a researcher. The Information Sheet enclosed provides further details about the study and what will happen if you agree to participate.

In order to make responding more convenient for you, I will follow up this letter with a brief e-mail. My e-mail address is also included at the top of this letter should you wish to contact me sooner with a response.

Yours sincerely

Eliel Cohen

PhD Researcher, University of Sheffield

### Appendix B.3. Information Sheet

You are invited to take part in a research project. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please feel free to ask for further information or clarification.

***The Research***

This project studies universities’ engagement with non-academic sectors of society. In order to identify examples of such engagement, I have drawn on universities’ submissions to the Impact element of the Research Excellence Framework (REF) 2014. The research has two main phases of data collection. You are being asked to participate in Phase 2.

Phase 1: Documents related to REF 2014 submissions

Information is collected from: (a) Impact and Environment Templates, (b) Impact Case Studies (c) academic outputs cited under the ‘References to the Research’ section of each selected Impact Case Study, (d) web pages of the relevant researchers, departments and schools and (e) web pages of other organisations described in the Impact Case Study as being important in the process of the research.

Phase 2: Interviews with researchers

This involves interviews with researchers associated with the Impact Case Studies (one researcher per Case Study). Interviews will focus on the research described in the Impact Case Study, particularly on the relationships and collaborations which underpinned the research. Some questions may also touch on more general experiences of being an academic researcher.

***Why have I been chosen?***

You have been identified as having been a key researcher underpinning one of the selected Impact Case Studies. As such, your experiences are of special relevance to my research.

***Do I have to take part?***

It is up to you to decide whether or not to take part. After having decided to participate, you can still withdraw at any time without giving a reason.

***What will happen to me if I take part?***

We will arrange an interview to take place at a time that is convenient for you, either in person or via a video calling programme (such as Skype). It should last up to approximately one hour. However, any time you can give for the interview will be much appreciated.

Prior to the interview, you will be asked to sign a Consent Form stating that you have been provided with this Information Sheet and have had the opportunity to ask any questions, and that you understand your right to withdraw from the study at any time without giving a reason.

***Will the universities be identified in the study?***

My study’s aims require that some details of the research underpinning the Impact Case Studies be provided in the report. Therefore, the universities whose Impact submissions have been selected will be identified in the research. However, my discussion of these will be based on documentary sources which are publicly available.

The aim of my research is not to evaluate institutions, departments or staff, nor to make any arguments that may negatively affect their reputation; indeed, the Impact Case Studies have all been selected precisely because they achieved a relatively high rating in the REF.

***Will my taking part in this project be kept confidential?***

Yes, your participation and information will be kept confidential. In order to ensure your anonymity in the report, discussion of interview data will be aggregated and separated from discussion of specific Impact Case Studies in the thesis. If you are concerned about being identified, you may request to see the relevant section of the thesis prior to submission.

***Will I be recorded? How will the recorded media be used?***

Yes, I intend to audio record the interview, which will be transcribed for analysis. Quotes used in any publications or presentations will not be attributed to you, and will be subject to the principles for safeguarding your anonymity as explained above. No other use will be made of them without your written permission, and no one outside the project will be allowed access to the data.

***What are the benefits of participating?***

There are no immediate benefits of participating. However, by deepening understanding of universities’ relationship with external organisations, the findings may be useful for those who work in or with the sector.

***What are the disadvantages of participating?***

There are no expected disadvantages beyond any inconvenience associated with the actual interview, which I will of course aim to minimise by conducting it at a time to suit you.

***What if something goes wrong?***

If there is anything that you are concerned about or would like to complain about, regarding the interview or any other aspect or outcome of your participation or the research, you can contact myself, my supervisor, or my Head of Department. All contact details are included on this form.

***What will happen to the results of the research project?***

The results will be published in my doctoral thesis, with a hard and soft copy available via the University of Sheffield. The results may also be used in future publications, such as journals.

***Who has ethically reviewed the project?***

This project has been ethically approved via the School of Education’s ethics review procedure. The School of Education is part of the Faculty of Social Science, which funds the research. The University’s Research Ethics Committee monitors the application and delivery of the University’s Ethics Review Procedure across the University.

***Contact details***

As the researcher I, Eliel Cohen, would be the main contact: [ECOHEN1@SHEFFIELD.AC.UK](mailto:ECOHEN1@SHEFFIELD.AC.UK)

My doctoral supervisor is Dr Vassiliki Papatsiba: [V.PAPATSIBA@SHEFFIELD.AC.UK](mailto:V.PAPATSIBA@SHEFFIELD.AC.UK)

The Head of School (Education) is Professor Elizabeth Wood: [E.A.WOOD@SHEFFIELD.AC.UK](mailto:E.A.WOOD@SHEFFIELD.AC.UK)

### Appendix B.4. Consent Form

Name of Researcher: Eliel Cohen

Participant Identification Number for this project: Please initial box

1. I confirm that I have read and understand the information sheet, dated 29.12.17, explaining the above research project and that I have had the opportunity to ask questions about the project.
2. I understand that my participation is voluntary and that I am free to withdraw  
   at any time without giving any reason and without there being any negative  
   consequences. In addition, should I not wish to answer any particular  
   question or questions, I am free to decline.
3. I understand that my responses will be kept strictly confidential.  
   I give permission for members of the research team to have access to my  
   responses. I understand that my name will not be linked with  
   the research materials, and I will not be identified or identifiable in the  
   report or reports that result from the research.

4. I agree to take part in the above research project.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name of Participant Date Signature

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Lead Researcher Date Signature

*To be signed and dated in presence of the participant*

Copies:

*Once this has been signed by all parties the participant should receive a copy of the signed and dated participant consent form, the letter/pre-written script/information sheet and any other written information provided to the participants. A copy of the signed and dated consent form should be placed in the project’s main record (e.g. a site file), which must be kept in a secure location.*

### Appendix B.5 Ethics approval letter

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Downloaded: 18/12/2018 Approved: 20/11/2017

Eliel Cohen

Registration number: 150215538 School of Education Programme: PhD in Education

Dear Eliel

PROJECT TITLE: Academic Structure and the Impact of Academic Research: A Sociological Analysis

APPLICATION: Reference Number 015962

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 20/11/2017 the above-named project was approved on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

University research ethics application form 015962 (dated 15/10/2017). Participant information sheet 1036115 version 1 (10/10/2017).

Participant consent form 1036108 version 1 (10/10/2017).

If during the course of the project you need to [deviate significantly from the above-approved documentation](https://www.sheffield.ac.uk/rs/ethicsandintegrity/ethicspolicy/approval-procedure) please inform me since written approval will be required.

Yours sincerely

David Hyatt

Ethics Administrator School of Education

## Appendix C. Document and webpage database

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| --- | --- |
| **Unit of Assessment 1** | |
| 1 | University of Glasgow (2014). REF2014 Impact Template. <https://results.ref.ac.uk/(S(5mhsdcrlek45dkop3v4uw5gx))/Submissions/Impact/394> |
| 2 | University of Glasgow (2014). REF2014 Environment Template. <https://results.ref.ac.uk/(S(5mhsdcrlek45dkop3v4uw5gx))/Submissions/Environment/394> |
| ***Body of Research 1.1*** | |
| 3 | University of Glasgow (2014). REF Impact Case Study no. 41138. <https://results.ref.ac.uk/(S(5mhsdcrlek45dkop3v4uw5gx))/Submissions/Impact/394> |
| 4 | University of Glasgow (2014). REF Impact Case Study no. 41144. <https://results.ref.ac.uk/(S(5mhsdcrlek45dkop3v4uw5gx))/Submissions/Impact/394> |
| 5 | University of Glasgow (2014). REF Impact Case Study no. 41155. <https://results.ref.ac.uk/(S(5mhsdcrlek45dkop3v4uw5gx))/Submissions/Impact/394> |
| 6 | Macfarlane PW. Age, sex and the ST amplitude in health and disease. J Electrocardiol. 2001; 34 (suppl):235-41. doi: 10.1054/jelc.2001.28906 |
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| 8 | Clark EN, Sejersten M, Clemmensen P, Macfarlane PW. Automated electrocardiogram interpretation programs versus cardiologists’ triage decision making based on teletransmitted data in patients with suspected acute coronary syndrome. Am J Cardiol. 2010; 106(12):1696-702. doi: 10.1016/j.amjcard.2010.07.047. |
| 9 | Macfarlane PW, McLaughlin SC, Devine B, Yang TF. Effects of age, sex, and race on ECG interval measurements. J Electrocardiol. 1994;27 Suppl:14-19 |
| 10 | Shepherd J, Cobbe SM, Ford I, Isles CG, Lorimer AR, MacFarlane PW, McKillop JH, Packard CJ. Prevention of coronary heart disease with pravastatin in men with hypercholesterolemia. West of Scotland Coronary Prevention Study Group. N Engl J Med. 1995; 333(20):1301-7. doi: 10.1056/NEJM199511163332001 |
| 11 | Emerging Risk Factors Collaboration et al. Major lipids, apolipoproteins, and risk of vascular disease. JAMA 2009; 11;302(18):1993-2000. doi: 10.1001/jama.2009.1619 |
| 12 | McCarey DW, et al. Trial of Atorvastatin in Rheumatoid Arthritis (TARA): double-blind, randomised placebo-controlled trial. Lancet 2004; 19;363(9426):2015-21. doi:10.1016/S0140-6736(04)16449-0 |
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| 14 | Preiss D, et al. Risk of incident diabetes with intensive-dose compared with moderate-dose statin therapy: a meta-analysis. JAMA 2011; 22;305(24):2556-64. doi: 10.1001/jama.2011.860. |
| 15 | Ford I et al., for the WOSCOPS Group. Long-term follow-up of the West of Scotland Coronary Prevention Study. N Engl J Med. 2007; 357: 1477–1486 doi: 10.1056/NEJMoa065994. |
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| 35 | <https://www.linkedin.com/in/marc-henis-a171b716/> (accessed 4 September 2019) |
| 36 | <http://www.uniqure.com/about/about-management-team-steve-zelenkofske.php> (accessed 4 September 2019) |
| 37 | <https://globenewswire.com/news-release/2017/06/06/1008503/0/en/uniQure-Announces-Appointment-of-Steven-L-Zelenkofske-as-Chief-Medical-Officer.html> (accessed 4 September 2019) |
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| 39 | <https://www.linkedin.com/in/susan-watkins-34613323/> (accessed 4 September 2019) |
| 40 | <https://clinicaltrials.gov/ct2/show/NCT00412984> (accessed 4 September 2019) |
| **Unit of Assessment 4** | |
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| **Unit of Assessment 5** | |
| ***Body of Research 5*** | |
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## Appendix D. Narrative accounts and plotted typologies of sampled Bodies of Research (BoRs)

I group the narratives of the n=19 bodies of research (BoRs) according to the ten different departmental, or ‘Unit of Analysis’ (UoA) REF2014 submissions with which they are associated. Under each BoR is its plotted typology. I provide some brief context of each department before describing the BoRs sampled from it.

### BoRs sampled from UoA 1

The five Impact Case Studies sampled from the nineteen which formed Glasgow’s UoA 1 submission are based on research in the Institute of Cardiovascular & Medical Sciences (ICMS). ICMS, like the broader College of Medical, Veterinary and Life Sciences within which it is situated, supports collaborations between clinical experts and life scientists. The five Impact Case Studies contribute to two distinct bodies of research (BoRs).

#### Body of Research 1.1: ‘Diagnosing and Treating Cardiovascular Conditions’

Titles of relevant REF Impact Case Studies:   
‘Advancing heart disease diagnosis – influencing international guidelines and commercial adoption of automated ECG analysis software’

‘Global adoption of statins for cardiovascular disease prevention’

‘Statin therapy: Patient selection, clinical guidelines and revision of safety labelling’

Phase 1. Diagnosis of cardiovascular conditions using automated analysis and interpretation  
An electrocardiogram (ECG) is a test whereby nodes are attached to a patient’s chest to measure the heart’s electrical activity, enabling the detection of abnormal activity and, potentially, diagnosis of underlying cardiovascular conditions. However, the accurate interpretation of ECG results in clinical contexts is complicated by the fact that what counts as ‘normal’ electrical activity varies from patient to patient, including across demographic characteristics such as age, gender and ethnicity. Glasgow’s ICMS researchers pioneered automated ECG analysis and interpretation of ECG results since the 1980s. From the 1990s, they began systematically studying the variations associated with these demographic characteristics and incorporating them into the automated diagnostic algorithms. Thanks to continuing refinement of the algorithms, automated ECG’s capabilities have now been found to be, on average, comparable, or even superior, to that of specialist cardiologists in diagnosing certain conditions.

Research under Phase 1 has generally been conducted as a core ICMS capability in partnership with local hospitals and therefore has no specific grant funding associated with it. The advances made by ICMS have influenced international diagnostic guidelines. Additionally, ICMS’ ECG algorithms have been commercialised and incorporated into many leading medical devices. As well as generating revenue and aiding accurate and efficient diagnosis for millions of patients each year, ICMS’ ECG algorithms have been crucial to the efficiency of large-scale, industry-funded trials of cardiovascular treatment drugs, as can be seen in Phase 2.

Phase 2. Randomised controlled trials of cardiovascular treatments (statins)  
High cholesterol levels are the main modifiable risk factor for cardiovascular disease, such as heart attacks. Statins are a class of drugs which lower cholesterol levels and are therefore potentially valuable as a treatment for the prevention of cardiovascular disease. From the 1990s, ICMS researchers conducted large, industry-sponsored randomised controlled trials of commercial statins. Due to the large sample and the multiple measurements required of each of the several thousand participants, accurate automated ECG readings and interpretations, enabled by the algorithms developed by ICMS in Phase 1, were crucial to the efficiency, reliability and feasibility of these trials in Phase 2. The results of the trials found significant reductions in heart attacks and heart disease in the statin group.

Although the original trials were funded mainly by industry, recent follow-up analyses of the lasting benefits of statins have been supported mainly by other public and charitable organisations.

Phase 3. Meta-analyses address concerns about the (over-)prescription of statins  
The benefits associated with statins saw them become the most-prescribed medicines in the United Kingdom and United States by the end of the 2000s. This has raised concerns about whether such widespread prescription was always medically appropriate, prompting ICMS researchers to conduct meta-analyses on their benefits and potential harm, both in general and within specific sub-groups. One general finding was that statins were found to be associated with a small increased risk of diabetes, but that this risk is significantly outweighed by the previously-identified benefits. In relation to one specific sub-population, ICMS showed that sufferers of certain types of arthritis are at a higher risk of cardiovascular disease and should therefore be considered for statins even if their cholesterol levels are normal. These findings have informed influential international guidelines, prompting them to re-state and/or extend their recommendations for the prescription of statins. Meta-analyses described here were primarily supported by non-industrial sources, such as research councils, charities, and the Scottish Government.

|  |  |
| --- | --- |
| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 2 3 1 |
| Goals | 1 2 3 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 1 3 2 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 3 1 2 |
| Boundary management | 1 2 3 |

Figure 17. Plotted typology. BoR1.1

#### Body of Research 1.2: ‘Treating Heart Failure’

Titles of relevant REF Impact Case Studies:

‘Landmark advances in outcomes for patients with heart failure’

‘Transforming the treatment of atrial fibrillation’

Phase 1. New methods, strategies and pharmaceutical treatments for heart failure   
From the mid-1990s, a core of leading ICMS researchers, in collaboration with industrial scientists, commenced a broad range of trials of new methods, strategies and drugs for the diagnosis and treatment of heart failure. Although the main focus was the testing of new drug treatments, the programme of research was interested in improving the whole treatment experience, and this required collaboration with expert nurses specialising in care of heart failure patients.

As well as showing the broad effectiveness of these new treatments, the large-scale nature of the trials enabled the researchers to analyse how they benefited different kinds of patients to varying degrees, for example in terms of their age, gender and medical history. This latter, a focus on sub-groups based on medical history, is taken up further in Phase 2.

Phase 2. Focusing on at-risk sub-populations and extending recommendations of medicines   
Generally, heart failure is associated with high cholesterol and/or blood pressure. However, some patients may have unrelated medical histories or conditions which put them at greater risk of heart failure despite having normal levels of cholesterol and blood pressure. This raises the question of whether the most effective treatments for heart failure caused by cholesterol or blood pressure are the same for heart failure caused by unrelated medical conditions. Phase 2 relates to ICMS research throughout the 2000s which focuses on one major such condition, atrial fibrillation (AF), a heart rhythm disorder, which had been found to increase risk of heart failure for normal cholesterol level patients.

Glasgow researchers either led or collaborated on several large, industry-sponsored randomised controlled trials of treatments for patients with AF who have suffered heart failure or heart attack. Treatments proven in these trials have been recommended in major guidelines globally.

Phase 3. Addressing concerns around drug treatments and testing non-drug alternatives  
By the late 2000s, drug treatments had become standard, but some studies had shown adverse effects on AF patients. There was thus emerging interest in testing the effectiveness of non-pharmaceutical alternative treatments, such as ablation. Ablation aims to physically destroy those areas of the heart or surrounding area which are responsible for AF symptoms. This is achieved by subjecting the affected area to either high or low temperatures, destroying the area such that it is prevented from sending electrical impulses to the heart, thereby bypassing the arrhythmia which the affected area was previously causing. In a government-funded study, ICMS researchers, in collaboration with a local Glasgow hospital, tested the effectiveness of ablation, finding that it was in fact less effective and less safe than standard drug treatments. This reinforced the value of drugs trials and related analysis conducted in Phases 1 and 2.

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| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 2 3 1 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Network | 2 3 1 |
| Social capital | 1 2 3 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 3 2 1 |
| Boundary management | 3 1 2 |

Figure 18. Plotted typology. BoR1.2

### BoRs sampled from UoA 4

Both of UEL’s Case Studies were based on research led by the School of Psychology’s Drugs and Addictive Behaviours Research Group (DABRG), whose members also established the wider Substance Use and Misuse (SUM) network, through which its research is further disseminated, particularly amongst policy actors and other user groups, although also bridging across other disciplines. DABRG’s own research is best described as belonging to the inherently interdisciplinary and use-inspired field of *psychopharmacology*, which is concerned with the effect of drugs on cognitive processes, behaviour and physiology. Within this disciplinary context, the main guiding principle for their research agenda has been delineating the extent of long-term health impacts and is thus oriented towards the more applied goal of producing information relevant to policymakers, health professionals and users. However, certain phases of DABRG research is interested in advancing a fundamental scientific understanding of the problems they address.

As will be shown, the research underpinning the two Case Studies follow largely similar trajectories: (a) DABRG researchers demonstrate the extent of negative psychopharmacological effects of a given drug; (b) these findings are developed with greater detail and specificity thanks to large research grants, in both cases from the United States Government’s National Institute for Drug Abuse (NIDA); (c) this mass of evidence is sufficient to overcome competing scientific interpretations and influence policy (among other impacts).

#### Body of Research 4.1: ‘Informing Smoking Policy’

Title of relevant REF Impact Case Study: ‘Informing public and policy debate about improving understanding of the effects of cigarette and e-cigarette smoking’

Phase 1. First demonstration of negative effects of nicotine on mood and cognitive function  
In the 1990s, the DABRG was involved in a debate about how to interpret the observation that smoking temporarily improves mood and cognitive performance. Some believed that these were genuine gains above normal ‘baseline’ levels. DABRG were able to dispel this interpretation by showing that after smoking, mood and cognitive skills did not return down to a ‘baseline’ but rather kept on deteriorating. DABRG were thus the first to demonstrate that psychological dependence on nicotine was responsible for long-term reduced mood and performance (rather than a temporary boost above normal levels of mood and performance).

Phase 2. Influencing tobacco control policy in the UK Health Act 2009  
Over the following decade, DABRG developed this research through a large NIDA grant. They gained a greater understanding of (a) the time course of psychological nicotine-withdrawal symptoms, (b) the length of abstinence necessary to recover from these symptoms, (c) the variations in the time-course of symptoms and recovery that different abstinent smokers experience, and (d) the effect of these variations on the likelihood of success when attempting to quit. This mass of evidence contributed significantly to the British Psychological Society’s (2008) consultation to the Department of Health and ultimately to the Health Act 2009 which introduced a national strategy to reduce smoking rates.

Phase 3. Meeting the new demand for knowledge of electronic cigarettes   
With the arrival on the market of electronic cigarettes (e-cigarettes), there arose a new demand for scientific knowledge on their effects on withdrawal symptoms and cognition effects. For the first time, DABRG found itself somewhat aligned with the interests of smoking product manufacturers; that is, both DABRG and e-cigarette companies lobbied (and continue to lobby) to make the case for e-cigarettes as less harmful alternatives to tobacco cigarettes. This new dynamic prompted two new lines of DABRG research: comparisons between the two types of cigarette; and research into the demographic patterns and factors in e-cigarette use. One DABRG researcher in particular has developed strong collaborative ties with the e-cigarette manufacturing industry “whose marketing strategies, lobbying activities and preparations for regulatory control have been directly informed” (UEL, 2014, p. 2) by her work.

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| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 1 2 3 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 19. Plotted typology. BoR4.1

#### Body of Research 4.2: ‘Informing MDMA Policy’

Title of relevant REF Impact Case Study: ‘Improving understanding among policy makers, the public and medical professionals of the potential harm that MDMA (Ecstasy) use may have on the neuro-psychological functioning of adults and babies’

Phase 1. Contributing to psychopharmacological understanding of MDMA (ecstasy)  
DABRG contributed to several scientific debates about the MDMA drug (popularly known as ecstasy), most significantly around two questions: Do the negative effects of MDMA outweigh apparent benefits? What psychopharmacological mechanisms underpin observed effects?

Based on systematic reviews and novel empirical studies, DABRG showed significant negative effects of MDMA on cognitive functioning and mood in both the short and long term. Moreover, they showed that the strength of these effects correlate with both frequency and quantity of MDMA use. Additionally, they provided strong evidence in support of their hypothesis that these effects are the direct result of damage to neurons which release a chemical (serotonin) that is associated both with the feeling of elation brought on by ecstasy pills and with cognitive functioning (e.g. memory).

Phase 2. Contributing to practical debates around MDMA  
Having advanced the scientific understanding of the causes and effects of MDMA, DABRG follow-up work focused on ascertaining the extent, nature and mediating factors (i.e. frequency, length and conditions of MDMA use) of negative effects in users. This research advanced understanding of the real-life contexts of MDMA use and its impacts. The strengthened body of evidence produced by this research influenced the UK Government’s decision to maintain MDMA’s status as a Class A drug, despite official recommendation that it be reduced to Class B.

Phase 3. Scientific advances prompt new demand for knowledge  
DABRG’s success in evidencing the long-term psychological damage of MDMA in adult users prompted a new concern about the effects that MDMA use by pregnant women may have on children. DABRG collaborated on a large, longitudinal NIDA-funded study into MDMA use of pregnant women and the cognitive effects on children at various intervals after birth. Their findings have been disseminated and discussed internationally via the media, governmental agencies, pregnancy and parenting websites, and medical professionals.

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| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 1 2 3 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 20. Plotted typology. BoR4.2

### BoRs sampled from UoA 5

From the University of St Andrews (henceforth St Andrews) I have selected four Impact Case Studies out of the six submitted to UoA 5. All four are based on research within the Sea Mammals Research Unit (SMRU). SMRU started life in 1978 within the Natural Environment Research Council (NERC), created to fulfil NERC’s obligation to advise the UK Government on seal management according to NERC’s Royal Charter and the Conservation of Seals Act 1970. SMRU was moved to St Andrews School of Biology in 1996, with NERC continuing to fund SMRU’s work related to advisory obligations. The overall discipline which best describes SMRU’s research is marine ecology, with particular focus on the interdisciplinary subfield of marine mammalogy. This implies that while SMRU research makes some fundamental advances in knowledge, ‘use’ of knowledge is a major driver of the research.

Beyond this underpinning epistemic context, the empirical content and context of the research underpinning the four Impact Case Studies have several commonalities which can be summarised under six interrelated themes: (a) the methodological framing of the empirical context as a complex ‘open system’ (i.e. the marine ecosystem); (b) this requires advances in technology and software for the collection and analysis of complex data; (c) the novel datasets produced by such technologies require development of new statistical techniques; (d) the inherent multi-disciplinarity of the study of sea mammals requires scientists to work towards shared, robust definitions of key concepts; (e) in order to influence society, scientists also need to construct concepts that are understandable to governing bodies and the wider public; (f) scientists must be sensitive to the socio-economic factors (e.g. fishing) associated with sea mammal depletion, as scientific evidence alone is insufficient to guide policy.

#### Body of Research 5: ‘Sea Mammal Research & Impact’

Titles of relevant REF Impact Case Studies:   
‘Animal-borne telemetry tags for conservation and weather forecasting’  
‘Mitigating environmental impacts of naval Sonar’  
‘Enabling industry compliance with offshore regulation’  
‘Marine Mammal Conservation: from policy to bycatch reduction’

Phase 1. Co-advancement of science and technology

Sea mammals, such as seals, are top predators in marine ecosystems, and thereby raise concerns about competition with fisheries, prompting calls for seal population controls. Sustainable control requires detailed knowledge about both population distribution and behaviour, particularly behaviour related to foraging habits. In short, seal management depends upon fundamental mammalogical knowledge, that is, zoological and ecological knowledge of sea mammals.

SMRU brings together an interdisciplinary group of experts, including ecologists, zoologists, statisticians and engineers. This provides the environment for a highly effective mode of operation in which scientific demand spurs technological developments, which in turn make new kinds of scientific question feasible. Throughout the 1990s, breakthroughs in SMRU research, instrumentation and software made significant advances in the scope of marine mammalogy. New SMRU technologies provided the ability to track seals’ at-sea behaviour, allowing greater levels of breadth and depth (literally) of data collection than ever before possible.

The knowledge and information gained through this mutually-sustaining cycle of science and technology has influenced a range of policies and initiatives around sea mammal control and conservation, as well as supporting the naval, oil/gas and fishing industries whose operations inevitably lead to interactions with, and therefore potential disturbances to, sea mammals. As such, these industries are subject to stringent regulatory compliance. SMRU technologies have enabled organisations within these sectors to comply with these regulations and have therefore become important to core operations.

Phase 2. Methodological innovations  
If advances in empirical and technological capacity develop roughly in synchronisation, then close behind them are methodological advances, primarily in the form of statistical innovations which aim to both estimate the error inherent in existing methods and to maximise the analytical potential of newly-acquirable data. For example, SMRU used their own technology to calculate the errors inherent in the satellite systems used by research groups around the world. In addition, they proposed and tested novel statistical methods for the analysis of complex data enabled by their and others’ new technologies.

SMRU’s aim of sharing their own innovations to as wide a relevant audience as possible can be seen in the publications associated with Phase 2, for example publishing in general ecology journals rather than marine ecology specific journals.

Phase 3. Disseminating technologies and techniques, generating revenueThe technological, methodological and theoretical advances prompted by SMRU’s scientific questions also have broader potential applications in conservation and conservation science, beyond mammalogy. Phase 3 centres around SMRU’s efforts to explore, develop and explain their technologies’ potential applicability by others, particularly other ecological scientists (beyond mammalogists) or sectors affected by conservation regulations.

Again, this calls for a broader audience, and this is reflected in the journals of these academic outputs, such as journals of relevance to biology in general rather than focused on (marine) ecology or mammalogy.

Moreover, successful dissemination of these technologies has resulted in significant financial returns, either through sales developed and sold through the SMRU Instrumentation Group, or through SMRU’s spin-out company SMRU Consulting.

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| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 2 1 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 2 1 3 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 21. Plotted typology. BoR5

### BoRs sampled from UoA 7

At Edinburgh Napier University (ENU), research related to UoA7, Earth Systems and Environmental Sciences, took place in the very broadly-titled School of Life, Sport and Social Sciences (although since REF 2014 this has been replaced by the similarly broad School of Applied Science). Both BoRs discussed below are associated with the still relatively broad Animals and Plants Science Research Group, which combines expertise on ecology, animal behaviour, veterinary science and parasitology, among other fields. A common thread across these areas of research is a focus on applying this expertise to the management and conservation of biodiversity and ecosystems, and this reflected in the specific centre with which the below BoRs are associated, namely, the Centre for Environmental and Marine Sciences and Services (CEMaSS). Within the context of CEMaSS, BoR7.1 can be located in the scientific sub-discipline of oceanography, while that of BoR7.2 has a more applied focus in conservation ecology.

#### Body of Research 7.1: ‘Defining and Sustaining Healthy Seas’

Title of Relevant REF Impact Case Study: ‘Defining and Sustaining Healthy Seas’

Phase 1. Understanding ‘normal’ sea conditions and what constitutes ‘unhealthy’ change  
Eutrophication is a process in which waste from human activity, such as from agricultural fertilizers or sewage, reaches a body of water, thereby increasing the availability of nutrients in the water to above normal levels and fuelling the accelerated growth of phytoplankton (algae) on the water’s surface. Following a process of eutrophication, phytoplankton, which survive by absorbing energy from the sun and nutrients from the water, can multiply to take up so much of the water’s surface as to reduce the levels of sunlight and oxygen reaching sea life below, with potentially harmful effects. Between 1996 and 2003, CEMaSS research increased understanding of the process of how human waste influences phytoplankton growth and, in turn, how this impacts sea life. CEMaSS produced models simple enough for policy and regulatory use which could predict the impacts of human waste in specific regions, particularly in EU seas.

Phase 2. ‘Assimilative capacity’ as a usable regulatory model  
The above research was explicitly oriented towards the general needs and regulations of EU countries. However, Phase 2 refers to even more direct efforts to provide political actors with an understandable and usable concept to understand the health and stability of European seas, but one still grounded in rigorous science. CEMaSS put forward the concept of ‘assimilative capacity’. This term summarises a model which assumes that all natural environments have the capacity to assimilate some level of acceptable change, and that only change beyond this level should be considered unacceptable. The ‘assimilative capacity’ model aimed to provide a formula for ascertaining what level of change a given region or environment could acceptably assimilate. CEMaSS were thus proposing a model which accounted not only for the latest oceanographic science but also for political realities, such as current regulation and the inevitability of clashing socio-economic interests (such as between regulators and farmers whose agricultural waste may cause eutrophication).

Phase 3. Directly influencing the parameters for legally acceptable human impact  
From 2004, CEMaSS received a pressing new impetus and remit to advance understanding of, and agreement on, what should count as ‘undesirable disturbance’ of human activities on waters. Research was commissioned by the Department for Environment, Food and Rural Affairs (DEFRA) in anticipation of a legal case made by the European Commission against the UK for failing to identify eutrophic waters in their jurisdiction. Based on the methods and parameters CEMaSS developed for ascertaining ‘undesirable disturbance’, the UK Government was able to win the case being made against it.

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| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 1 2 3 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 22. Plotted typology. BoR7.1

#### Body of Research 7.2: ‘New Paths to Mangrove Conservation’

Title of relevant REF Impact Case Study: ‘New Paths to Mangrove Conservation’

Phase 1. Demonstrating the full value of mangroves  
Mangroves are known to be environmentally and economically valuable as carbon sinks, as a habitat for important fish species, and as a protective barrier for coastal communities against potentially damaging waves (i.e. tsunamis). However, in poor East African coastal communities, such as Gazi in Kenya, mangroves suffer high rates of destruction for other economic purposes such as aquaculture and timber extraction. In the 2000s, CEMaSS made important methodological advances to conduct research which better demonstrated the full value of mangrove preservation, as these can often be underestimated. For example, CEMaSS developed a technique for comparing the chemical information in samples of water with the chemical information in the cells of captured fish. By studying different ages and species of fish, they were able to show that mangroves provided the most important ‘nursery’ habitat for commercially-important juvenile fish, even for many fish species which do not predominantly inhabit mangroves as adults. CEMaSS therefore enabled an even stronger long-term case to be made for mangrove preservation.

Phase 2. Establishing scientific insights as essential to preservation and regeneration   
CEMaSS then expanded their focus to the issue of how best to protect, manage and potentially regenerate mangrove environments. They conducted experiments on small areas of mangrove to discover the most effective species and densities of trees to optimise carbon capture and fish habitation.

Although this research advanced fundamental ecological knowledge, the most significant outcome was showing conservation managers that scientific experimentation could be a valuable management tool.

Phase 3. Ecosystem recovery through the sale of ecosystem services (‘carbon credits’)  
Hoping to advance not only knowledge but also conservation practice, CEMaSS aimed to demonstrate the feasibility of an innovative model of conservation and regeneration in which the local community would work to restore and conserve mangroves. The community would be paid for this work by the sale of ‘carbon credits’, whereby any company or individual around the globe can offset their own carbon footprints by funding the project’s work.

For this model to work and be seen as credible, further scientific research was needed in calculating the environmental value of the community work (i.e. how much carbon-offsetting is achieved by the planting of a given number of trees). However, such an ambition clearly required the backing not only the ecological scientists, but a range of other actors, including from within the community itself. Reflecting the wider, more impact-oriented and interventionist goals of this research then, co-grant holders included not only academics but also individuals from the Kenya Marine and Fisheries Research Institute (KMFRI), an official national scientific body which would manage the project on the ground, as well as private sector specialists in sustainability management analytics, who would help to produce analytical software to support KMFRI’s management of the project.

A direct outcome of the research was the establishment of ‘Mikoko Pamoja’ (Swahili for ‘Mangroves Together’), which operationalises this project long-term and is now fully funded by carbon credit sales. Researchers, governments and conservationists are now working to export this highly successful model to other coastal African communities.

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| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 1 2 3 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 23. Plotted typology. BoR7.2

### BoRs sampled from UoA 8

Queen’s University Belfast (QUB) ranks first in the UK on two indicators of successful transfer and commercialisation of knowledge: total revenue generated by intellectual property; and number of Knowledge Transfer Partnerships (KTPs) (government-sponsored industry partnerships delivered by Innovate UK). In this institutional culture, it is not surprising that there is significant industry engagement in the Impact Case Studies discussed below, based on research from the School of Chemistry and Chemical Engineering. The partnerships underpinning the Case Studies can be understood as typical of the School’s research and impact model, in which individual experts in chemical engineering are expected to identify and secure funding for the development of solutions to problems, particularly those faced by large industry.

#### Body of Research 8.1: ‘Biocatalysts for Industrial and Medical Applications’

Title of relevant REF Impact Case Study: ‘Biocatalysts for Industrial and Medical Applications’

Phase 1. Technical advances in biochemistry for broad industrial applications  
The production of new medicines often relies on so-called ‘intermediary’ bioproducts which, themselves, are not therapeutic, but which enable new medicinal biochemical syntheses. These intermediary bioproducts are in turn produced through a process of ‘biocatalysis’ (the transformation of organic compounds using enzymes). In the 1990s, research led by the QUB’s Centre for Theory and Application of Catalysis (CenTACat) in collaboration with industrial scientists developed new techniques for manipulating these biocatalytic processes. The goal was not the development of any specific new medicine, but rather of new techniques and a new class of bioproduct with a broad range of potential applications to industrial drug development.

Nearly a decade after this original research, CenTACat staff were employed by a Canadian pharmaceutical company for an amount of one of their novel bioproducts to support development of a new drug. Such was the effectiveness of this bioproduct, and the new medicine that it helped produce, that the result was a licensing deal worth potentially $600 million for the company.

Phase 2. Developing bioproducts with more targeted applications  
Since 2000, CenTACat have worked on bioproducts with more specific applications, such as bioproducts with known cancer treatment applications. This is reflected in sources of funding and collaboration for this research, which include a range of state and other non-profit actors as well as industry (e.g. the US Public Health Service and various departmental and non-departmental government bodies of Northern Ireland).

Phase 3. A symbiotic relationship between academic and industry research groups  
Much of this more recent research has been collaborative with Northern Ireland-based pharmaceutical and biotechnology company, Almac Sciences. The closeness of this particular relationship is based on and sustained by the frequent transfer of knowledge from CenTACat to Almac Sciences. This knowledge exchange takes two main forms: (i) collaborative projects and co-authored papers, and (ii) Almac Science’s employment of CenTACat PhD graduates (which numbered fifteen at the time of the School’s REF2014 submission, making up half the workforce of Almac’s Biocatalysis Group). This close relationship has underpinned significant research and commercial advances in the production of new marketable drugs and is set to grow yet stronger following a $7 million investment in a formal QUB-Almac Sciences Biocatalysis Partnership, announced in 2015, and partly funded by the Northern Ireland Government and the European Union.

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| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 1 2 3 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 24. Plotted typology. BoR8.1

#### Body of Research 8.2: ‘Mercury Capture Technology for the Global Petroleum Industry’

Title of relevant REF Impact Case Study: ‘Mercury Capture Technology for the Global Petroleum Industry’

Phase 1. Demonstrating environmental benefits of ionic liquids as ‘green’ industrial solvents  
Throughout the 1990s, QUB researchers led the case for using ionic liquids (ILs) as environmentally superior ‘green solvents’ in a wide range of industrial contexts. Initially, it was only amongst industrial actors that the researchers found interest and research funding support. Eventually, however, able to obtain funding from research councils and other sources, QUB scientists made fundamental contributions to understanding and demonstrating the solvent properties of a range of different ionic liquids, with the primary objective of building up a database of materials and the range of potential applications.

Successful demonstration of the potential of ionic liquids led to the establishment in 1999 of the Queen’s University Ionic Liquids Laboratory (QUILL), run as an industry-academic consortium whereby projects are decided either based on the collective interests of its fee-paying industry members or on a one-to-one basis with an individual industrial sponsor. The creation of QUILL signalled the recognition of the high potential of ionic liquids. Nonetheless, some early QUILL outputs still had the aim of making the case for ‘green solvents’, for example one paper wrote of the continuing need “to facilitate general acceptance and to promote the use of ILs” (Holbrey et al., 2002, p. 407), explaining that “despite the significant developments that have been made in both understanding the properties, and exploring the utility of ILs, they are still generally considered esoteric materials ” (Holbrey et al., 2002, p. 407).

Phase 2. Deepening fundamental knowledge for applied purposes  
Despite the apparent ongoing need to persuade of ionic liquids’ value at the beginning of the decade, QUILL’s main aim throughout the 2000s was to advance fundamental understanding of ionic liquid structure and behaviour in various complex environments. The ultimate goal of this fundamental knowledge, however, was the refinement of applied predictive models about the behaviour and effectiveness of ionic liquids in various industrial contexts.

Phase 3. University-industry collaboration to realise ionic liquid’s potential in practice  
This use-inspired basic research provided the knowledge necessary for more effective applied research aiming to determine the most appropriate ionic liquid for given contexts, for example, the removal of sulphur from diesel fuel, or the removal of mercury from natural gas supplies. Based on the latter example, QUILL attracted a £5.25 million investment from Malaysian oil and gas company, Petroliam Nasional Berhad (Petronas) in 2008. In collaboration with Petronas, QUILL co-developed and co-patented a technology for the industrial removal of mercury, a toxic and corrosive contaminant naturally present in hydrocarbon supplies. This technology has since received a record-breaking number of awards from the Institute of Chemical Engineering as well as the Royal Society of Chemistry’s ‘Teamwork in Innovation Award’ and has been described by the British Museum as the most important British innovation of the twenty-first century.

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| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 2 1 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 2 1 3 |
| Goals | 1 2 3 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 1 2 3 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 25. Plotted typology. BoR8.2

#### Body of Research 8.3: ‘Practical Raman Chemical Analysis for Forensic Applications’

Title of relevant REF Impact Case Study: ‘Practical Raman Chemical Analysis for Forensic Applications’

Phase 1. Demonstrating the application of ‘spectroscopy’ to the Forensic Science Agency  
Spectroscopy refers to the application of controlled radiation, as in X-rays for example. In the late 1990s, researchers at the School’s Innovative Molecular Materials Research Centre (IMMRC) recognised the potential of spectroscopy as a method for the analysis of forensic materials, thanks to its ability to provide detailed material information whilst also being non-destructive. In collaboration with the Forensic Science Agency in Northern Ireland (FSNI), including via the sponsorship of PhD students, IMMRC demonstrated the feasibility of such analysis, in the first instance applied to the analysis of illicit drugs (primarily ecstasy).

The technique was later applied to other materials such as paint, often crucial in forensic analysis of serious crime cases, but normally a difficult and costly task.

Phase 2. Developing the practicability of routine forensic spectroscopy  
Far from the above being the conclusion of knowledge transfer, however, it marked the start of a long-term partnership in which IMMRC were committed to ensuring FSNI were able to maximise the effectiveness of spectroscopy, while in turn, IMMRC were given access to scientifically and technologically challenging research problems.

This included, for example, developing spectroscopic capabilities to not only identify substances in illicit drugs, but to distinguish between different batches of large samples of drugs with sufficient specificity so as to enable their identification with specific sources (i.e. manufacturers and distributors) – a crucial step in forensic intelligence and, ultimately, prosecution. From 2004, FSNI implemented IMMRC’s spectroscopic techniques in their regular operational analysis of all ecstasy, and from 2008, of all white powders.

As with Phase 1, the analysis of paint followed a similar trajectory, with analysis becoming sufficiently proven and technically mastered by 2010 to be incorporated into routine analysis of all FSNI paint casework.

Phase 3. Ongoing expert support for new kinds of forensic challenges  
Several years later, the government and FSNI faced a significant new legislative and intelligence challenge in the form of ‘cathinones’, a broad family of drugs popularly known as ‘legal highs’. These drugs flooded the market in 2009 and were not illegalised until 2010. Such was the novelty, diversity, and pace of change in the chemical make-up of these ‘legal highs’, that FSNI’s immediate aim was merely to categorise these novel drugs into differently-composed compounds, and then to test the ability of spectroscopic techniques to distinguish between these chemically similar compounds. FSNI renewed their collaboration with IMMRC experts, whose analysis showed that spectroscopy was indeed capable of meeting these needs, thereby significantly advancing the prosecution and intelligence capabilities of the authorities.

|  |  |
| --- | --- |
| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 3 2 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 1 3 2 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 26. Plotted typology. BoR8.3

### BoRs sampled from UoA 9

Research submitted by the University of Cardiff (henceforth Cardiff) to UoA 9 is based at the School of Physics and Astronomy. Two different, but closely-related research groups are responsible for the research. These are the Astronomy Research Group (ARG) and the Astronomy Instrumentation Group (AIG). ARG specialises in research relating to the formation of stars and galaxies, while AIG specialises in technological and engineering for the production of instruments designed for space travel. Generally, AIG underpins Phases 1 & 2 below, while ARG research underpins Phase 3. However, it is important to bear in mind that there is significant communication, knowledge exchange and interdependence between the two groups.

What is clear is that within both these two groups, and indeed the School more generally, there exist strong pathways to various kinds of impact and several individuals with a strong personal commitment to traversing these pathways. This includes, for example, commitments to applying technologies in other beneficial contexts (e.g. environmental or health contexts), and to public outreach and disseminating astronomical findings to the general public and young people. As will be seen, these goals are not simply add-ons, but are considered worthy of significant time and planning, and are well-integrated into the work and culture of the School at several points, including through academic experts with dedicated outreach roles, and through a spin-out company dedicated to translating the School’s research into valuable technologies in a range of contexts.

#### Body of Research 9: ‘Astronomical Research and Instrumentation’

Titles of relevant REF Impact Case Studies:  
‘Terahertz (THz) detection from the distant universe to the international market’

‘The *Herschel* Space Observatory: scientific and technical outreach’

Phase 1. Instrument development for astronomical and other applications  
The AIG focuses on developing technologies and instruments which meet the demands and drive the advancement of cutting edge astronomy. AIG’s researchers maintain a close and mutually-beneficial relationship with the ARG, which focuses on fundamental astronomical science. Within this relationship, AIG are kept up to date about the scientific demands of astronomy, while ARG are kept up to date about technological advances and the new scientific possibilities which they provide.

As well as maintaining close links with ARG, another major collaborator is AIG’s spin-out company, QMCI, founded in 1971 and co-located with AIG in the School of Physics and Astronomy building. AIG work closely with QMCI both in the fulfilment of specific projects, such as the European Space Agency (ESA) projects discussed in Phase 2, as well as for the general advancement of scientific and astronomical instrumentation. QMCI staff sometimes co-author academic papers with AIG, but their main role is to provide a mechanism for the translation of AIG technologies to new areas of application by bringing them to, and in some cases adapting them for, the global market. For example, technologies originating in AIG have been sold for use in biomedical imaging, fusion power (nuclear fusion for renewable energy), and atmospheric sensing for use in environmental and meteorological research.

However, rather than simply relying on market processes for the dissemination and application of AIG technologies, the School allocates academic staff time to actively seek and engage with potential users (academic and non-academic) of AIG technologies. For example, the Deputy Head of AIG also holds the role of the School’s Director of Innovation and Engagement. This involves seeking and engaging with a wide range of sectors which might be interested in the technologies and other outputs from the School as a whole, and the AIG especially. Along with a second AIG professor, he is personally involved in applying AIG technologies in environmental research which uses satellite observations of earth to gather data. A third AIG professor collaborates with experts in biophysics and optometry (eyecare science and practice) to develop AIG technology for application in these fields.

Phase 2. Applying instruments to observatories in large space programmes  
Thanks to AIG’s leading expertise in developing astronomy instrumentation, in particular in electromagnetic radiation detectors (similar to X-rays, but for different wavelengths), AIG researchers have had significant involvement in the development of on-board instruments for two major ESA missions. The first, and larger of the two projects, was the Spectral and Photometric Imaging Receiver (SPIRE) project. Cardiff was the lead institution out of eighteen institutions from eight European countries collaborating on the £90 million project. The SPIRE instrument served as a detector to be placed on ESA’s *Herschel* space telescope, whose total cost was nearly £1 billion. The second project, on which Cardiff was a collaborating institution, was the High Frequency Instrument (HFI) placed on board the ~£700 million *Planck* telescope. Both the Herschel and Planck telescope missions lasted from 2009 to 2013, but the production of their on-board instruments constituted a significant proportion of AIG research for over a decade from 1990s to the 2000s.

The scientific and technical challenges associated with implementing technologies into a functioning satellite in the extreme conditions of a take-off are significant. They call upon far larger forms of collaboration than, for instance, AIG’s development of specific devices in collaboration with QMCI and in consultation with ARG, as in Phase 1. This can be illustrated by the large number of authors on papers related to the SPIRE instrument, one of which names nearly 200 co-authors; and even these would not account for all who worked on the instrument, for example private companies which produce or engineer certain parts.

Indeed, the multiple nations and multiple kinds of organisation involved mean that considerable management skill is essential among the academic leadership of such projects. Even prior to the commencement of such projects, the decision by ESA about which nations will be involved and which will take the lead are inherently political in the context of an agency funded by multiple nations, so that scientific and technological expertise are not the sole criteria for engagement in a given ESA project.

Phase 3. Curiosity as a driver of a combined science and outreach strategy  
Data obtained by the Herschel and Planck satellite telescopes have enabled researchers, primarily in the ARG but sometimes in collaboration with AIG, to answer questions and advance theories of fundamental interest about the universe. For example, the data has been used to answer questions about how stars are formed and how galaxies evolve in the long run (over billions of years).

Alongside this curiosity-inspired basic scientific research, a significant minority of the work and output of AIG and ARG is less cutting edge but still considered a key goal and responsibility of the School, complementary to and directly following from its cutting edge research. These other activities include outreach, production of popular science outputs, and scientific communication (e.g. via scientific and mainstream media outlets). As was seen in Phase 1 in relation to disseminating innovative technologies to various sectors and research fields, there is significant dedication within the School to engage with these outreach and other communication activities and, as will be shown below, significant scope for career recognition through them. This commitment can be seen in both the general structure and culture of the two groups (AIG & ARG) and the wider School, as well as in specific outreach activities directly associated with the School’s SPIRE funding. I describe these below.

With regards to the School-wide culture, the Head of ARG writes popular science books (including a book, not yet published, about Herschel aimed at a non-scientific audience). Meanwhile, the Deputy Head has, for several years, also served as the School’s Head of Public Engagement and Chair of the Outreach Committee and, in 2018, was awarded as Member of the Order of the British Empire (MBE) for services to science communication and promotion. The School also has part-time staff whose main professions are in science communication. For example, one part-time lecturer, who also was awarded an MBE for services to science outreach and communication in 2017, is the founding director of *science made simple*, a social enterprise which runs science outreach programmes, particularly in schools. Another part-time lecturer is the Education Director of Las Cumbres Observatory, an international non-profit company which operates a network of telescopes and connects these via the Internet, allowing access to anyone and therefore of great value in public and school outreach activities. Both these part-time lecturers are provided office space by the School to conduct both their university and non-university activities, and both have played significant roles in showcasing, disseminating, educating and enthusing the public based on Cardiff’s astronomy research and technology.

The SPIRE project, as well as being a good example of the School’s overall research expertise and operational model, is also an excellent example of the AIG’s commitment to wider impact. The AIG-based SPIRE team secured nearly £200,000 for outreach activities directly associated with the SPIRE project and the broader Herschel programme (and this figure is only a fraction of the total outreach and engagement funding awarded to the School during the REF period). Part of this funding was expended on employing one of the SPIRE/Herschel postdoctoral researchers as a dedicated, half-time Herschel Outreach Officer, in which role he set up and maintains a well-visited website aimed at both expert and non-expert audiences discussing the project and related issues of fundamental astronomical interest, as well as organising a range of Outreach events. He has since become the Ogden Lecturer within the school, supported by the Ogden Trust, which promotes the teaching and learning of physics throughout society.

Throughout the School, there is a sense that curiosity-based astronomical research into the formation of galaxies and stars is considered incomplete until it is disseminated publicly in the hope of satisfying and stimulating the natural curiosity of society, particularly potential future scientists.

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| --- | --- |
| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 3 1 2 |
| Relevance | 3 1 2 |
| Disciplinary focus | 2 3 1 |
| Uncertainty | 1 3 2 |
| Goals | 3 2 1 |
| Learning | 1 2 3 |
| Knowledge exchange | 2 1 3 |
| Network | 1 2 3 |
| Social capital | 1 3 2 |
| Accessibility | 2 1 3 |
| Outputs and outcomes | 2 1 3 |
| Evaluation | 2 1 3 |
| Flexibility | 3 2 1 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 27. Plotted typology. BoR 9

### BoRs sampled from UoA 10

This is the second of two submissions selected from Glasgow and is submitted by Glasgow’s School of Mathematics and Statistics. Statistical methodologies clearly have a significant and growing role in practically all contemporary sciences and industries. In this sense, the two Case Studies below are similar, in that both depend on innovations in statistical methodologies directed at particular contexts.

However, the two Case Studies also exhibit differences, and this reflects primarily the differences in the kinds of sectors and actors with which Formal scientists might collaborate. The first of the two, having developed expertise in a particular statistical methodology, somewhat serendipitously found themselves being sought after as collaborators by a large multi-national company, who saw the strategic potential of developing these methodologies in ways specific to their operations, and whose size enabled them to make the kind of long-term partnerships and investments that academic researchers seek. The other case is of academic research inputting into the highly science-dependent area of clinical medicine.

#### Body of Research 10.1: ‘Monitoring Groundwater Pollution’

Title of relevant REF Impact Case Study: ‘Development of an innovative data analysis tool to monitor groundwater pollution and environmental impact’

Phase 1. Advances in statistical methodologies and software  
Throughout the 1990s and 2000s, Glasgow statisticians, led primarily by one professor, have made significant advances in developing new statistical methodologies for application in a broad range of scientific and industrial contexts. Keen to encourage the broadest relevance and uptake of their outputs, the researchers have always developed these methodological tools whilst bearing in mind the latest and most popular computational statistical packages. More recently, they have taken this further by codifying these innovations within a new add-on package for ‘R’, one of the most widely-used computational statistical applications.

Phase 2. Knowledge transfer and industrial application through graduate employment In 2005, a doctoral graduate from the Glasgow School of Mathematics and Statistics, having been supervised by the leading professor underpinning this Case Study, was employed by the multinational oil and gas company Royal Dutch Shell, commonly-known as Shell, working within its UK-based Shell Global Solutions division. Within a year, and as a direct result of the expertise brought by this boundary-spanning statistician, Shell Global Solutions began work on the potential application of these Glasgow-developed statistical methods to groundwater monitoring. Monitoring the potential pollution of groundwater as a result of oil and gas extraction activities is an essential aspect of the industry. However, standard approaches to this monitoring have sometimes been hindered due to the statistical complexities of making inferences about wider areas based on the small samples of measurements of pollutants that can be practically obtained. There was therefore significant scope for improvements in groundwater monitoring methods and sample analysis techniques, with likely improvements in the speed with which leaks or spills could be identified, as well as efficiency gains in the amounts of sample required.

So began a research relationship between the School and Shell. The initial work, resulting in co-authored papers, focused on further methodological improvements in spatiotemporal modelling (the analysis of sparse data collected over time and space). As will be seen in Phase 3, this relationship continued thanks to the strong potential Shell saw in this analytical approach and the funds they were willing to invest.

Phase 3. Collaborative development of new industry-specific analytical software   
As the relationship between the School and Shell developed, Shell became more aware of the potential value of not only the School’s statistical techniques, but also of their software outputs, also described in Phase 1. From the late 2000s, this university-industry partnership took on a new dimension and shared goal as the academic team worked with the company to make adaptations to this software for an industry-specific analytical tool. The result was the Groundwater Spatiotemporal Data Analysis Tool (GWSDAT) software, developed primarily for Shell use, but also available to other industrial and regulatory users. Having implemented GWSDAT from 2009, Shell have since then funded a PhD student at Glasgow to focus full-time on further refining the software, and as a result of these investments achieved an estimate of at least $10 million in savings up to 2014.

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| --- | --- |
| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 3 2 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 1 2 3 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 28. Plotted typology. BoR10.1

#### Body of Research 10.2: ‘Quantification of the benefits of statins’

Title of relevant REF Impact Case Study: ‘Quantification of the benefits of statins’

Phase 1. Conducting a large clinical trial on a controversial but high-potential drug  
In 1988, Glasgow statisticians became involved in a bid to conduct a trial of ‘statins’, cholesterol-lowering drugs, for a large pharmaceutical company. Some scientific and media controversy surrounded statins. Some research had shown cardiovascular health benefits, while some observational studies had associated statins with increased risk of heart disease and even death from unrelated causes, such as cancer and even murder.

Despite this, the bidding team believed that there was a high potential for statins, particularly in Scotland where the rate of heart disease was higher than any other country in the world. They designed a clinical trial of statins on individuals who, demographically, could be considered at-risk but had no history of heart disease. The bidding team were unique in proposing to study individuals with no history of heart failure, and this preventative objective was a significant factor in their being awarded the trial, known as the West of Scotland Coronary Prevention Study (WOSCOPS).

Statins’ controversy hindered participant recruitment. Only with great effort from the institutional partners and leaders, hundreds of health professionals, and the large team of data collectors which made up the WOSCOPS team, over a period of more than two-and-a-half years and around 150,000 patient visits, were the team were able to identify, screen, and recruit an appropriate number of consenting participants (approximately 6,600 in total). This was followed by more than 130,000 follow-up visits for all participants over a five-year trial period. The trial confirmed significant health benefits of statins, including a 31% reduction in coronary events and a 28% reduction in deaths from coronary heart disease. Crucially, no significant negative effects of statins were identified.

Phase 2. Methodological innovations to enable long-term follow-up of participants  
After having collected and analysed the massive amount of data described in Phase 1, the WOSCOPS leaders were keen to continue the follow-up of patients in order to understand the longer-term effects of statins. This required two kinds of methodological innovation to address two significant challenges, the first practical, the second analytical. Both were ultimately delivered by the Glasgow Centre for Biostatistics.

The major practical challenge was how to physically check up on participants. After around seven years of data collection and around 280,000 patient visits, securing funds to continue this level of on-the-ground support was unfeasible. Near the end of the data-collection, Glasgow created a doctoral studentship which would focus on the feasibility of using digitally-stored records of patients to act as a method for collecting follow-up data, rather than patients needing to be physically called in for the sole purpose of follow-ups. It was shown that the results that would have been achieved by using digital data were almost exactly the same as the actual results that had been achieved by physical follow-ups throughout the five-year trial period. After completing the PhD, the student in question was hired by the Government to work on the digital patient data system, and future follow-ups (see Phase 3) were able to implement this approach.

The second challenge related to a widespread confusion and misunderstanding, even amongst medical statistical experts, about the methodological step from analysing results of long-term trials to predicting the actual effects of treatment on given patients in clinical settings. This predictive capability, although not essential to demonstrating the general effectiveness and safety of a drug (the concern of industry), is very important clinically (the concern of health practitioners), particularly in health systems free at the point of contact, because the strength of a prediction will affect costing decisions (the concern of Government) about which sub-groups (age, health status, gender etc.) of a population should be offered the treatment, when, and for how long. The breakthrough development in the statistical treatment of this issue resulted in the relevant Glasgow staff to be invited to discuss this work and its implications both at a major conference of the Royal Statistical Society and in a major medical statistics journal.

Phase 3. Long-term follow-ups of WOSCOPS   
The ten-year follow-up (referenced in the Case Study) and all subsequent five-yearly follow-ups (the twenty-five-year follow-up is now under way) have all depended on the two methodological innovations achieved in Phase 2. The record-linkage methodological innovation has massively reduced the labour-intensity and levels of funding required for follow-ups, these requiring only relatively modest grants from health organisations or the Scottish Government. And the statistical innovation has allowed more accurate predictions of the treatment effects of statins and helped to prompt the up-take of statins in medical guidelines and practice globally. The follow-up studies continue to show a range of significant long-term health benefits of cholesterol-lowering statins without significant negative side-effects.

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| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 2 3 1 |
| Uncertainty | 1 2 3 |
| Goals | 2 1 3 |
| Learning | 1 3 2 |
| Knowledge exchange | 2 3 1 |
| Network | 2 1 3 |
| Social capital | 2 3 1 |
| Accessibility | 2 3 1 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 3 2 1 |
| Human capital | 1 2 3 |
| Boundary management | 2 3 1 |

Figure 29. Plotted typology. BoR10.2

### BoRs sampled from UoA 11

The University of Portsmouth’s Faculty of Technology contributes two BoRs, *‘Clinical outcome modelling saves lives’* and *‘Improved mobility and quality of life for children with disabilities’*, delivered by two separate research units, respectively, the Centre for Healthcare Modelling and Informatics (CHMI) and the Systems Engineering Research Group (SERG). The two units, CHMI and SERG, each focus on leveraging interdisciplinary research networks and professional practitioner networks in order to maximise the relevance and impact of their applied research.

#### Body of Research 11.1: ‘Clinical outcome modelling saves lives’

Title of relevant REF Impact Case Study: ‘Clinical outcome modelling saves lives’

Phase 1. An auditing system for comparing surgical outcomes across hospitals  
In the 1980s, there was increasing interest in the auditing of surgical practice in order to enable comparisons between hospitals and to enable benchmarking of successful surgical outcomes, as well as to identify best practice. This prompted research aimed at producing a basis for standardising outcomes in different contexts which would take into account factors known to affect chances of successful surgery, e.g. old age or a history of health conditions. The most widely-accepted research-based audit system which had been proposed was known as ‘POSSUM’ (Physiological and Operative Severity Score for the enUmeration of Morbidity and mortality). In the early 1990s, an interdisciplinary team of doctors, medical physicists and statisticians from Portsmouth NHS Trust and the CHMI embarked on a collaboration to test and improve such audit systems. The team identified significant limitations in POSSUM, finding that it over-predicted the average death rate of surgery (with some sub-groups over-predicted by a factor of seven). Based on new data and improvement to the POSSUM model’s formula, the Portsmouth NHS/CHMI team were able to significantly improve the model’s predictive capabilities, thus making the model more fit for purpose. They called the new model ‘Portsmouth-POSSUM’ (P-POSSUM).

Phase 2. Developing an Early Warning System (EWS) for real-time clinical care   
For the following decade, into the early 2000s, this collaboration continued and further consolidated with the appointment of one NHS medical physicist as Professor of Health Informatics at CHMI. This professor became the main link between the partner institutions and led the development of this Phase of research in two main directions. First, it broadened in scope by applying P-POSSUM to general medicine cases rather than only to surgery outcomes. Second, it moved closer to being of direct relevance to clinical care. It achieved this by showing, in principle, how the P-POSSUM model could be (i) sufficiently simple in terms of requiring only vital signs data already routinely collected by hospitals of their inpatients, and also (ii) sufficiently powerful in predictive capability to be of use to clinical care in real-time. In other words, the model could be used as an Early Warning Score (EWS) to instantaneously identify and rank patients most at-risk of deterioration and therefore of extra monitoring and care.

Phase 3. Developing and disseminating the EWS for routine hospital use in NHS and beyond  
Developing the EWS into a workable system for widespread application throughout a hospital and, potentially, the NHS more generally, required two new kinds of partnerships to be established.

The first, starting in the mid-2000s, was with private sector specialists in medical informatics. This partnership centred around developing a commercial product to digitise the process of inputting the patient data and refining the algorithm which generates the EWS, as well as digitally disseminating the EWS to relevant staff around the hospital. At the time of the REF submission, the company had sold the resultant technology to more than 20 hospitals.

Second, CHMI also wanted to make a non-commercial version of their EWS available for free to the NHS. The team worked with the Royal College of Physicians (RCP) in order to deliver this. At the time of the REF submission, the RCP had recommended for the NHS to fully adopt the final version of CHMI’s EWS, and it had already been adopted in other countries.

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| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 1 2 3 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 30. Plotted typology. BoR11.1

#### Body of Research 11.2: ‘Improved mobility and quality of life for children with disabilities’

Title of relevant REF Impact Case Study: ‘Improved mobility and quality of life for children with disabilities’

Phase 1. Industrial collaboration to develop mobile artificial intelligence (‘walking robots’)  
Since the late 1980s, Portsmouth’s Systems Engineering Research Group (SERG) began collaborative work with industry on so-called ‘expert systems’, an advanced form of artificial intelligence in which computer systems are designed for making the decisions of an expert human in a particular context. The main industrial collaborator was Nuclear Electric, the company which ran British Electric upon the sector’s privatisation. Industry’s main interest was the development of ‘walking robots’ which could be used as inspectors. The sector’s high technological demands and strategic importance for the nation enabled SERG and its industry partners to attract research council funding. This collaboration is ongoing, and the paper referenced under Phase 1 is a recent example of such work. The expertise developed by SERG through this research has been crucial to future work relevant to the impacts described in the Case Study.

Phase 2. Engaging wheelchair users, care professionals and experts  
From the early 1990s, SERG began applying their expertise in mobile robots and automated guided vehicles to so-called ‘rehabilitation technology’, specifically the functionality of wheelchairs. Throughout the decade, a significant part of the work towards achieving this involved the systematic engagement with rehabilitation and other care and related professionals, as well as wheelchair users themselves. For example, SERG initiated visits to ‘special schools’ (specialising in inclusive environments) and hospitals. SERG were quickly able to establish a collaborative relationship with one special school, which was particularly fruitful since this school also employed its own in-house specialist engineer who provided an important source of expertise and collaboration, and eventually was appointed to a University post in addition to his school role. Conversely, medical professionals tended to be more “reluctant” and “suspicious” [11.2.1, p. 466] of technological solutions. Relationships with medical professionals improved as the value of SERG’s work was demonstrated through their school collaborations as well as through symposia hosted by SERG which brought together various experts and stakeholders.

These relationships were crucial for SERG’s access to users and natural data-collection sites, as well as establishing a direct pathway to impact. Work published under this Phase was also more directly targeted at user groups, for example [11.2.4] is SERG’s first publication aimed directly at the rehabilitation professional community.

Phase 3. Long-term work with rehabilitation experts, professionals, manufacturers and users  
The substantive research and development centred around artificial intelligence systems which would equip wheelchairs with improved capacities to learn from its environment and its specific user. For example, these advances: improved the wheelchair’s ability to automatically avoid collisions; improved the manoeuvrability of the wheelchair, thus reducing the burden on the user; allowed the wheelchair to learn to tolerate a level of involuntary movements of the user; and endowed the wheelchair with the capacity to adapt its responsiveness to the user. These technologies have been achieved in collaboration with wheelchair manufacturers, schools, charities and the NHS, and with support from research councils and Innovate UK (for example through a KTP).

The technologies have mostly impacted children and individuals with complex needs, both directly through the provision of improved wheelchairs, and indirectly by impacting professional services.

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| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 3 2 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 3 2 |
| Knowledge exchange | 1 3 2 |
| Network | 1 3 2 |
| Social capital | 1 3 2 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 3 2 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 31. Plotted typology. BoR11.2

### BoRs sampled from UoA 13

University of Cambridge (hereby Cambridge) research in the Department for Materials Science & Metallurgy (DMSM) underpins this UoA 13 submission. Researchers in DMSM apply expertise in physical and chemical engineering to practical contexts. The two sampled Case Studies below represent the two broad approaches to this. The first is an instance of delivering technology to large industry. The second exemplifies the significant infrastructure and incentive DMSM offers its researchers to develop patentable technologies over which the researcher can receive highly favourable terms of ownership for spin-outs and patents which result from their academic research. In both Cases, patents are important academic outputs, and this is reflected by their being heavily referenced in the Case Study documents as representative of the quality and significance of the underpinning research.

#### Body of Research 13.1: ‘High-performance nanostructured-steel armour

Title of relevant REF Impact Case Study: ‘High-performance nanostructured-steel armour’

Phase 1. Collaboration with the Ministry of Defence to improve steel performance  
Many metals, including steel, are crystalline in their nanostructure, that is, they are made up of microscopic crystallites or ‘grains’. It is known that metals made up of a greater number, but smaller size of grains are stronger than metals made up of fewer, larger grains. Based on this knowledge, in the late 1990s, DMSM researchers, in partnership with the Ministry of Defence (MoD), commenced work on processes which would reduce grain size of steel. The main end product of this research was the aim of improving the performance of steel used in the manufacture of armoured vehicles.

This combined effort yielded significant theoretical discoveries about nanostructures, as well as patentable novel techniques for manipulating and manufacturing hardened steel known as ‘bainite’, which had been discovered in the early twentieth century but was previously little-understood.

Phase 2. Collaborating with industry for wide-scale manufacture and application of bainite  
The patented processes held by the MoD, which had resulted from work described under Phase 1, was licensed to Tata Steel (then known as Corus). Industrial-scale production required further research and development, now in a ‘triple helix’ (Leydesdorff & Etzkowitz, 1998) industry-government-academia collaboration. This resulted in new patents held by all three parties. The improved steel was found to be superior to existing products and able to be produced cost-effectively. As a result of this industrial collaboration, one leading MSM researcher was endowed as the first Tata Steel Professor of Metallurgy.

Phase 3. Disseminating wider theoretical and applied implications of underpinning research  
Phase 3 refers to efforts at summarising the theoretical and applied research in such a way as to steer future lines of inquiry. The aim is to focus researchers’ efforts on those areas which will most likely lead to application and commercialisation, so that attempts to advance *understanding* are driven by goals of *use*. This objective is reflected in the shift in publishing practice. Outputs from earlier Phases were published in journals promoting “fundamental and technological aspects”[[27]](#footnote-27) of materials. By contrast, the journal in which the paper referenced under Phase 3 is published has a more direct focus on applications: “Emphasis is placed on ... issues at the forefront of the field, such as energy and environmental issues, as well as medical and bioengineering applications”, with a “particular interest [in] nanostructured/nanoscales materials”[[28]](#footnote-28).

Recent research conducted since that referenced in the Case Study, by both DMSM and others, has revealed more about why greater amounts of carbon (which is largely responsible for the strength of steel) are retained in the process than earlier theory would have predicted, and is also moving into new areas of application, such as the mining and rail industries.

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| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 3 2 |
| Relevance | 1 3 2 |
| Disciplinary focus | 1 3 2 |
| Uncertainty | 1 2 3 |
| Goals | 3 1 2 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 3 2 |
| Network | 1 2 3 |
| Social capital | 1 2 3 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 3 2 |
| Evaluation | 1 3 2 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 3 2 |

Figure 32. Plotted typology. BoR13.1

#### Body of Research 13.2: ‘Topical oxygen therapy for wound healing’

Title of relevant REF Impact Case Study: ‘Topical oxygen therapy for wound healing’

Phase 1. Aqueous electrochemistry & hydrometallurgy engineering  
The Materials Chemistry Group (MCG), located within DMSM, has particular strengths in the related areas of aqueous electrochemistry and hydrometallurgy. Aqueous electrochemistry exploits the properties of water molecules and their elementary components (i.e. hydrogen and oxygen) as conductors. Hydrometallurgy involves study of the reactions between water and its component elements with metals. One of the potentially broad range of applications of such expertise is in the generation of oxygen, for example by understanding how water reacts with metals and manipulating conditions (i.e. humidity) so as to produce the desired effect.

Phase 1 refers to underpinning research conducted by MCG into aqueous electrochemistry and hydrometallurgy, specifically around creating oxygen generators based on the electrochemical interaction between water and metal. As will be described below, the results of this research were crucial to MCG’s later development of a wound-healing device.

Phase 2. Applying expertise to develop an oxygen-generation and distribution system  
In the early 2000s, whilst at a chemical engineering conference, one leading MCG researcher came across an oxygen-generation device to aid the healing of wounds. Following the presentation, this researcher believed, based on MCG’s expertise described under Phase 1, that the device could be significantly improved upon by better controlling the relationship between water and metal when a small electrical voltage is applied. The researcher believed it would be possible to concentrate the distribution of this generated oxygen around the wound, thus greatly speeding the healing process.

Already having significant experience of intellectual property and founding spin-out companies, the researcher cofounded a new company with a long-time non-academic collaborator which would focus on the design of a new oxygen-distribution system. He was also successful in recruiting a postdoctoral researcher to focus on developing other aspects of the device. These two collaborative enterprises led to two separate patents, both of which ultimately were brought together in the final product (Phase 3).

Phase 3. Engaging the health sector and marketing the final product  
Finalising the product and making it available to medical professionals brings a new phase and also a new set of collaborations. Like all new medical products, the device was rigorously scrutinised, particularly at the stage of obtaining ethical approval for conducting the necessary trials. Even after ethical approval was granted, UK hospitals were found to be unresponsive. Hospitals expected a financial incentive for trialling the product and (as was seen in the case of UoA 11 Case Study II) were sceptical of proposed technological solutions to long-standing problems – in this case, the problem of healing chronic wounds, ulcers, burns etc. As such, the initial trials were not able to be conducted within NHS hospitals and were instead conducted in Czech Republic, which was also known to have appropriate ethics procedures and experience of carrying out trials. MCG being comprised of engineers rather than medical researchers, the trials themselves were outsourced to a specialist private medical consultancy known through MCG’s wider network.

These trials also served as a kind of market research and product development project. They identified practical issues that users had with understanding and using the device, for example how to maintain it, recharge it, etc. This prompted more user-friendly amendments to be made where necessary. One of the results was a further patent (referenced under Phase 3) which incorporates a portable oxygen-generator within the device, reducing the need for battery recharging.

|  |  |
| --- | --- |
| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 1 2 3 |
| Accessibility | 1 3 2 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 33. Plotted typology. BoR13.2

### BoRs sampled from UoA 14

The research is based in the Department of Civil and Structural Engineering. The two BoRs are based at the University of Sheffield Department of Civil and Structural Engineering, through the Vibration Engineering Section (VES) and Water Engineering Group (WEG), respectively. Both are focused on practical management issues for industry (construction and water), and proceed through applied projects conducted within specific companies, whose findings provide the basis for “fundamental engineering research”[[29]](#footnote-29) in order to influence wider engineering knowledge and practices, primarily through engineering guidelines, codes and regulations.

#### Body of Research 14.1: ‘Managing full scale dynamic performance of civil infrastructure’

Title of relevant REF Impact Case Study: ‘Managing full scale dynamic performance of civil infrastructure’

Phase 1. Influencing building codes and guidelines vibration performance of large structures  
In the mid-1990s, researchers at Sheffield’s Department of Civil and Structure Engineering initiated the Vibration Engineering Section (VES) to conduct research in vibration performance of large structures, such as buildings and stadiums, in response safety concerns as well as modern design demands. VES secured EPSRC funding initially with the objective to conduct research which would increase the knowledge base underpinning national and international building codes and guidelines. Based on the findings of this research, which analysed the impact of human walking and jumping, first in laboratory conditions and then in the field, VES’ outputs continue to be cited in building codes and guidelines which are recognised internationally and have legal status in the case of court actions.

Phase 2. Delivering more immediate impact through consultancy and industrial collaboration  
VES had engaged in consultancy research and industrial collaboration from its outset. However, in the 2000s, this took on new levels. For example, VES led on an EPSRC grant involving multiple private organisations which aimed to improve other aspects of existing guidelines, which were perceived to overburden some modern building design techniques and therefore unnecessarily increase building costs. This research required the development and validation of new tools for verifying performance. By 2008, VES created a spin-out company, Full Scale Dynamics Limited (FSDL), through which to conduct consultancy work. FSDL gave the VES team a more accessible, responsive and agile mechanism for engaging and serving clients.

The consultancy work and academic work support each other: the majority of consultancy work directly applies tools and expertise developed through funded research and published papers; similarly, work done on a consultancy basis has also contributed to academic outputs, including those referenced under Phase 2.

Phase 3. Major advances through large research grants  
By the mid-2000s, VES had built up significant expertise, knowledge and data on the relationship between structural vibration performance and human movement, i.e. walking, running, jumping. However, it remained the case that there was no reliable model for understanding the dynamic forces produced by human movement. As such, no formal guidance existed on how to account for these forces. Much of the difficulty is the unpredictability of human movements, including speed, weight, type of movement and its timing, etc. VES proposed research which would enable the appropriate statistical and probabilistic analysis of human forces. The knowledge and expertise built up in previous Phases was essential to these proposals, which required gathering a very large database of different movements and forces, and therefore a much larger EPSRC grants than had previously been awarded. In 2009, VES secured the field’s first EPSRC platform grant (designed to give increased flexibility to the grant holders) to help develop these statistical models. Although this Phase of the research did not involve industrial partners directly, the high value potential of the research to the construction industry was a major rationale for the grant application. Since the REF 2014 submission, VES have continued to increase their EPSRC grant funding, recently with a strategic equipment grant of over £3 million, and in this case multiple industrial partners have been directly involved in the grant, with the resulting equipment to be available for rent for commercial as well as academic research purposes.

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| --- | --- |
| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 3 2 |
| Disciplinary focus | 1 3 2 |
| Uncertainty | 1 3 2 |
| Goals | 1 3 2 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 3 2 |
| Network | 1 2 3 |
| Social capital | 1 2 3 |
| Accessibility | 1 3 2 |
| Outputs and outcomes | 1 3 2 |
| Evaluation | 1 3 2 |
| Flexibility | 1 3 2 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 34. Plotted typology. BoR14.1

#### Body of Research 14.2: ‘Management of discolouration in drinking water distribution systems’

Title of relevant REF Impact Case Study: ‘Management of discolouration in drinking water distribution systems’

Phase 1. A model for predicting and managing water discolouration   
From the early 2000s, a small team from the EPSRC-funded Sheffield-based Water Engineering Group (WEG) commenced a programme of research on discolouration of drinking water in collaboration with water companies. Discolouration is the biggest cause of customer complaints regarding water quality and is therefore a significant expense for water companies. The industry previously understood discolouration to be primarily the result of normal processes of sediment transporting from river environments into the water system. However, based on analysis of material responsible for discolouration, WEG proposed an alternative model for understanding discolouration in which material builds up in cohesive layers on the walls of pipes. This build-up interacts with the water in different ways in different hydraulic conditions, which can sometimes lead to displacement of material in sufficient amounts to cause discolouration. The body of research in Phase 1 refers to WEG’s developing and validating this novel model for the ‘Prediction and management Of Discolouration in Distribution Systems’ (PODDS).

Phase 2. Implementing risk-based computational tools for water management practice  
In the second half of the decade, based on the new model developed in Phase 1, research moved onto a more practical phase of using the model to inform management practice. WEG, in collaboration with several water company collaborators, developed computational management tools. These took a risk-based approach which would allow the data gathered to input into management decisions around when to intervene with “capital or operational strategies to manage discolouration risk” [14.2.4, p. 113].

With the increased amount of data gathered from a broader group of companies and a longer period of time, it emerged that trunk mains represented a major, but previously little-considered source of discolouration, with the industry assumption traditionally being that discolouration is due to issues in localised pipes. Trunk mains were now identified as worthy of particular strategic focus in the short-term, leading to Phase 3.

Phase 3. Maximising impact by focusing on an ignored but major cause of discolouration  
Research in Phase 3 aimed to test the extent to which trunk mains were responsible for discolouration. The approach to data collection and analysis was broadly similar to that of Phase 2 research. However, due to the particular interest in trunk mains, the researchers adopted a case study approach, whereby field data-collection focused on a single trunk mains system and associated local pipes, and this was supplemented with a spatiotemporal analysis of the timing and location of customer complaints within the region. Of the three Phases, the described here had the most immediate implications for management decisions of water companies, since a focus on managing trunk mains obviously has broader benefits across the whole associated water system and is therefore potentially more cost-effective than reacting only to local events and complaints. Accordingly, the paper under Phase 3 is the only one referenced in the Case Study on which an industry engineer collaborated as a co-author.

WEG’s PODDS work is ongoing and continues to focus on informing management decisions for its many water company partners, providing them with an opportunity to mutually learn from each other by combining their data through the research tools developed by PGW. The provision of this opportunity for mutual learning is an important role played by the neutral university in this otherwise competitive industry in which such data would normally be considered highly sensitive.

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| --- | --- |
| **Attribute/activity** | **‘Bounded’ ‘Unbounded’**  **1 2 3 4 5** |
| Expertise | 1 2 3 |
| Relevance | 1 2 3 |
| Disciplinary focus | 1 2 3 |
| Uncertainty | 1 2 3 |
| Goals | 1 2 3 |
| Learning | 1 2 3 |
| Knowledge exchange | 1 2 3 |
| Network | 1 2 3 |
| Social capital | 1 2 3 |
| Accessibility | 1 2 3 |
| Outputs and outcomes | 1 2 3 |
| Evaluation | 1 2 3 |
| Flexibility | 1 2 3 |
| Human capital | 1 2 3 |
| Boundary management | 1 2 3 |

Figure 35. Plotted typology. BoR14.2

## Appendix E. McNie, Parris and Sarewitz’s (2016) original typology



1. The ‘boundary’ metaphor has gained some currency amongst theorists of higher education and of universities’ social and economic roles (for example, Bacevic, 2017, 2018; Barnett, 2017; Beck & Young, 2005; Bernstein, 2000; W. C. Clark et al., 2016; Hatakenaka, 2004; Koryakina, Sarrico, & Teixeira, 2015; May & Perry, 2013b, 2017; McNie, Parris, & Sarewitz, 2016; Nickolai, Hoffman, & Trautner, 2012; Pawley, 2012; Primeri & Reale, 2015; Sataøen, 2018; Slaughter, Archerd, & Campbell, 2004; Vakkuri, 2004; Whitley, 2000; Wright, 2016; Ziman, 1991). [↑](#footnote-ref-1)
2. There have been some quite important technical changes implemented for REF2021, but I will not discuss these in any detail here. [↑](#footnote-ref-2)
3. The actual Impact rating is based on a judgement about the ‘reach’ and ‘significance’ of the impact, rather than on the perceived quality of the underpinning research, although there is a requirement that all research underpinning an Impact Case Study must be of a quality equating to at least a 2\* Output rating. [↑](#footnote-ref-3)
4. The concept of use-inspired basic research is put forward by Stokes (1997) in his efforts to modify the way that many, particularly in research policy discourse, define and think of the contribution and aims of research. Rejecting the traditional pair of dichotomies, in which understanding/use are the goals of basic/applied research, he pointed to Pasteur’s microbiology and Keynes’ macroeconomics as examples of his new of category of use-inspired basic research, which has since gained currency. [↑](#footnote-ref-4)
5. The relationship between society, classification and knowledge is elsewhere taken up explicitly by Durkheim and Mauss (1969). As Bloor (2005) summarises, they show how society is “constitutive of” (p. 80) knowledge. [↑](#footnote-ref-5)
6. However, even where the ‘costs’ are not directly financial, there are likely to be indirect financial costs of transacting; attempts to quantify transaction costs across the whole US economy found that “more than 45 percent of national income was devoted to transacting” (D. C. North, 1990, p. 28), that is, to the institutional upkeep, auditing, regulating, etc. of transactions across all forms of organisational and sectoral boundaries. [↑](#footnote-ref-6)
7. Although Bhaskar is most commonly portrayed as the main individual founder of critical realism, differing versions do exist, as discussed by Maxwell (2012). [↑](#footnote-ref-7)
8. The insight that “it is the nature of objects that determines their cognitive possibilities for us” (Bhaskar, 1998b, p. 27) – which Bhaskar initially applies to the possibility of our knowledge of society itself – also underpins Young’s (2008) theory of disciplinary knowledge. Critical realist philosophy thus fundamentally, albeit sometimes indirectly, influences my understanding of the notions of knowledge and disciplinarity. [↑](#footnote-ref-8)
9. Maximum variation sampling has been used in other research and theory-building contexts which are both theoretically and empirically close to my own. For example: B.R. Clark (1983) explores the range of ways in which national systems of higher education can be organised and co-ordinated by applying maximum variation to his comparative sample of different national systems; Cantwell (2015) investigates the different strategies used by laboratory managers in US universities of varying levels of prestige and research intensity; Bernstein’s (2000) research reveals variations in identity-formation in various knowledge-based contexts (i.e. teaching, learning, research); lastly, Greenhalgh and Fahy (2015), in their multiple case study of approaches to impact in community health research, “selected a maximum variety sample to illustrate the full breadth of research designs and approaches to impact” (p. 3). [↑](#footnote-ref-9)
10. I am not suggesting that Basic research cannot also have applied implication or goals, or that scientists in these disciplines do not conduct applied research; nor that Applied research cannot raise new challenges for basic science or, in some circumstance, directly advance fundamental understanding (Stokes, 1997; Ziman, 2005/1994). [↑](#footnote-ref-10)
11. I have removed the names of the institutions from this table so as not to draw attention to the individual universities here, but rather to focus on what is important about their contexts in relation to my study. However, the institutions are not anonymised in this study, and are named elsewhere in this thesis. [↑](#footnote-ref-11)
12. Environment Templates provide valuable information about the context in which the research is conducted, the departmental structure, its place in the wider institution, its approach to collaborations, and its role in supporting and engaging students, all of which will be relevant to my analysis. [↑](#footnote-ref-12)
13. Appendix B gives an indicative interview schedule, but it should be noted that the conversations were designed to be relatively open and free-flowing, and that they were partly tailored to each individual. [↑](#footnote-ref-13)
14. See Appendix E for the original typology. [↑](#footnote-ref-14)
15. Indeed, the concepts of ‘knowledge’ and ‘narrative’ are etymologically linked through the Latin root, *gna-* (*gnarus*, *gnarare)*, meaning ‘a telling’, from which both English words are derived (Bruner, 2003; Kvernbekk & Frimannsson, 2013; Torell, 2005). [↑](#footnote-ref-15)
16. This aggregation is obtained by placing all typology values in a single spreadsheet within Microsoft Excel, with each value categorised to its specific BoR and attribute/activity. I then use Excel’s ‘sum’ and ‘average’ functions to generate the aggregate values. [↑](#footnote-ref-16)
17. I am not suggesting that all instances of ‘outreach’ in my sample were homogenous, but only indicating that I have not examined or drawn on this heterogeneity in my analysis. [↑](#footnote-ref-17)
18. Note that this table only counts each boundary transaction once per BoR, so each boundary transaction can only receive a maximum frequency of nineteen (as there were n=19 BoRs sampled). However, in practice, some BoRs exhibited the same type of boundary transaction more than once. [↑](#footnote-ref-18)
19. Note that the three ‘phases’ are all grounded on key landmarks internal to each individual BoR, so that ‘Phase 1’ in one BoR may not be strictly comparable to ‘Phase 1’ in another. However, almost all BoRs did exhibit an increase in typology value from earliest to latest phases, and this finding is captured in the averages presented here. [↑](#footnote-ref-19)
20. See <https://www.nhs.uk/conditions/ssri-antidepressants/side-effects/> [↑](#footnote-ref-20)
21. QUILL website available at <https://www.qub.ac.uk/schools/SchoolofChemistryandChemicalEngineering/Research/QUILL/> (accessed 19 January 2017). [↑](#footnote-ref-21)
22. QUILL’s pre-history involves nearly two decades of scientific research and argumentation, much of which went against prevailing mainstream scientific opinion, preferences and priorities. The individual mainly responsible for founding QUILL wrote about his earlier rejection of research council funding in 1982 to investigate the potential industrial application of ionic liquids (Seddon, 1997): the first referee “stated that the systems were far too complicated, and therefore would never have any application”, the second “that the systems were far too simple, and the work was not worth doing”, and the third appeared to respond to the wrong proposal (p. 351). And fifteen years later, only two years before the establishment of QUILL, he was still experiencing scepticism, rhetorically opening his paper by asking: “Ionic liquids? Neoteric solvents? Molten salts for clean technology and catalysis? Are you serious?? Well, yes, I am serious” (Seddon, 1997, p. 351). [↑](#footnote-ref-22)
23. See for example <http://www.chromoscope.net/> and <http://herschel.cf.ac.uk/>. [↑](#footnote-ref-23)
24. The term ‘token’ scientist expresses the respondent’s opinion that he may have only been invited to the discussion to add scientific credibility, but that he may not in fact have been influential in shaping policy decisions. [↑](#footnote-ref-24)
25. I acknowledge that academic identity is a contested term and one that has not been the conceptual focus of this thesis. Therefore, I do not aim to make general claims about academic identity, apart from to note that a particular conceptualisation of academic identity helps to explain the boundary-transacting experiences associated with several BoRs studied. [↑](#footnote-ref-25)
26. The recent news around the funding of the Massachusetts Institute of Technology’s ‘Media Lab’ is perhaps an example of how the integrity of ‘academic boundaries’ of even the most powerful academic institutions is at risk in the context of a sector increasingly driven by external sources of power. Media Lab’s funding model rests mainly on a corporate sponsorship basis, whereby sponsors are entitled to shape the broad themes of research, and profit from intellectual property. Its director recently resigned due to revelations about one of its sources of funding (<https://www.theguardian.com/commentisfree/2019/sep/14/how-mit-was-complicit-in-allowing-jeffrey-epstein-to-launder-his-reputation>, accessed 22 September 2019). [↑](#footnote-ref-26)
27. This precise wording is used in both *Materials Science and Technology* and *ISIJ International*, where Phase 1 & 2 research was published. [↑](#footnote-ref-27)
28. This is from the ‘Scope of Journal’ statement for *Science and Technology of Advanced Materials*. [↑](#footnote-ref-28)
29. This expression is taken from the University of Sheffield’s ‘Environment Template’ document (p.1), part of its REF2014 submission to Unit of Assessment 14. This document is among the 345 I draw on for data analysis, and the full reference is provided in Appendix C. It mirrors the idea of “fundamental technology” put forward by the OECD (CERI, 1982, p. 144). [↑](#footnote-ref-29)