SPRU
Science Policy Research Unit

Working Paper Series

SWPS 2016-02 (January)

This version: July 2018

Institutional Shaping of Research Priorities: A Case Study on Avian Influenza

Matthew L. Wallace and Ismael Ràfols

University of Sussex

SPRU Working Paper Series (ISSN 2057-6668)

The SPRU Working Paper Series aims to accelerate the public availability of the research undertaken by SPRU-associated people, and other research that is of considerable interest within SPRU providing access to early copies of SPRU research.

Guidelines for authors

Papers should be submitted to swps@sussex.ac.uk as a PDF or Word file. The first page should include: title, abstract, keywords, and authors' names and affiliations. The paper will be considered for publication by an Associate Editor, who may ask two referees to provide a light review. We aim to send referee reports within three weeks from submission. Authors may be requested to submit a revised version of the paper with a reply to the referees' comments to swps@sussex.ac.uk. The Editors make the final decision on the inclusion of the paper in the series. When submitting, the authors should indicate if the paper has already undergone peer-reviewing (in other series, journals, or books), in which case the Editors may decide to skip the review process. Once the paper is included in the SWPS, the authors maintain the copyright.

Websites

SWPS: www.sussex.ac.uk/spru/research/swps

IDEAS: ideas.repec.org/s/sru/ssewps.html

Research Gate: www.researchgate.net/journal/2057-6668_SPRU_Working_Paper_Series

Institutional shaping of research priorities: a case study on avian influenza

***Matthew L. Wallace*[1,2] *and Ismael Ràfols*[1,3]**

[1] Ingenio (CSIC-UPV), Universitat Politècnica de València, València, Spain

[2] International Development Research Centre, Ottawa, Canada

[3] Centre for Science and Technology Studies, Leiden University, The Netherlands

Highlights

- We analyse the debates surrounding avian influenza research
- We document the landscapes of scientific activity on influenza and associated outcomes
- We find that research agendas are not directly driven by expectations of societal outcomes
- Instead, agendas are shaped by institutional pressures such as private-sector priorities and academic incentives
- The contested nature of influenza research points to the need for more explicit deliberations on priority setting

Abstract

Since outbreaks in 2003, avian influenza has received a considerable amount of funding and become a controversial science policy issue in various respects. Like in many other global and multidisciplinary societal problems fraught with high levels of uncertainty, a variety of perspectives have emerged over how to "tackle" avian influenza and public voices have expressed concern over how research funds are being allocated. In this article, we document if and how research agendas are being informed by public policy debates. We use qualitative and quantitative approaches to examine the relations between expectations of outcomes of public science and the existing research landscape. Interviews with a cross-section of stakeholders reveal a wide range of perspectives and values associated with the nature and objectives of existing research avenues. We find that the landscape of public avian influenza research is not directly driven by expectations of societal outcomes. Instead, it is shaped by three institutional drivers: pharmaceutical industry priorities, publishing and public research funding pressures, and the mandates of science-based policy or public health organizations. These insights suggest that, in research prioritization, funding agencies should embrace a broad perspective of research governance that explicitly considers underlying institutional drivers. Deliberative approaches in public priority setting might help to make agendas more plural and diverse and thus more responsive to the contested and uncertain nature of avian influenza research.

1. Introduction

A central question in science policy is how the research system can be mobilized to help tackle global, multi-faceted, societal challenges, particularly those that emerge rapidly. Research can be part of a broader response to what are broadly viewed as security threats such as climate change, malaria or antibiotic resistance. These issues involve a range of stakeholders with different understandings and expectations as to what the problems and risks are, what specific solutions should be sought, what role science and technology should play and how research should be configured to address the challenge. The question of managing research and allocating resources according to societal needs has been so far focused on prioritisation between competing problems. This has been mostly explored in the area of public health. For example, scholarship has explored whether or not the funding for different diseases is commensurate with their burden (Agarwal & Searls, 2009, pp. 867–869; Evans, Shim, & Ioannidis, 2014; Rafols and Yegros, 2018). However, there is less literature exploring how research governance has an effect on research prioritisation for (or within) a given challenge – which affects not only how resources are allocated and but also what type of research is conducted and what type is not (e.g. epidemiology vs. molecular biology of HIV) (Frickel et al., 2009; Ciarli and Ràfols, in press).

Public scrutiny over research prioritisation is often about demonstrating “value for money” (i.e. efficiency), focusing on the “right” priorities, as well as more generally being responsive to public concern over how research is undertaken and used. There is no optimal solution for how resources should be allocated, particularly if the issue is found to be highly contested and uncertain. In this vein, scholars and practitioners have called for more inclusive processes of deliberation (Stirling, 2007b) and for more consideration to debates happening both within the scientific community and particularly to disparate framings and perspectives from broader public spheres (Leach et al. 2010; Sarewitz, 2016). We can thus view the research and the research problem itself as being co-constructed as a scientific and political object by both scientific and political institutions (see, for example, Jasanoff, 2004). The question we explore in this article focuses on describing the various processes and institutions involved in funding and shaping priority setting, which take place in the absence of a centralized process.[1]

From Weinberg’s work over 50 years ago to today, the notion of priority-setting has proven to be a rich concept from which to address science policy challenges (Hellstrom & Jacob, 2012; Weinberg, 1963). This study broadly follows Laudel & Gläser’s (2014) conceptual framework to understand the governance of research: individual researchers “freely” choose research topics, but their choices are influenced by institutional contexts. By focusing on the issue of research prioritization, we aim to deepen our understanding of the links between research governance (as felt by individual researchers via a variety of institutional pressures), research contents and the social outcomes of such research.

Research prioritization, and funding allocation in particular, like the production and application of new knowledge itself, cannot be separated from the dominant institutional contexts and pressures. By

[1] Let us make clear that we do not advocate for centralised priority setting processes, which might be very vulnerable to capture by particular interests or incumbent institutions. Yet we also believe that it is helpful to visualise that there are ‘de facto’ or implicit priority setting processes and that current lack of explicit prioritization exercises is likely to lead to questionable outcomes.

“institutions” we refer here to norms, values and practices that ‘embody routinized “ways of going on” that, even when largely taken for granted by individual members of society, nevertheless continuously shape or channel social choices, constraining certain courses of action and enabling others’ (Frickel and and Moore, 2008, p. 8). These institutions are usually associated with formal organisations (companies, universities, national research funders, international organizations, etc.), as structures with their specific norms and values that influence the behaviour of researchers, policymakers and users of scientific knowledge.

Institutions play a key role in priority-setting and determine to a large extent the types of scientific and societal outcomes of research produced (Heinze, Shapira, Rogers, & Senker, 2009).Broadly speaking, the notion of institutional shaping of knowledge, rooted in the sociology of science (Gläser and Laudel, 2016), allows us to explore how the choices by scientists are influenced towards certain problem framings (Leach et al.,2010) which produce certain types of research outcomes and associated technologies (Williams and Edge, 1996).

This paper builds on studies arguing for a more systemic questioning of research agendas in order to foster diversification and alignment with perceived societal needs or demands (Stirling, 2007a; Pielke and Sarewitz, 2007; Sarewitz, 2014). It is part of a series of recent efforts to map research landscapes and portfolios as a means to understand priority setting (Cassi et al., 2017; Ràfols and Yegros, 2018; Ciarli and Ràfols, in press). In a previous paper, we explored how a “research portfolio” framing might help in science policy deliberations on a given topic, by mitigating uncertainty regarding research outcomes, and by improving the linkages between research “supply” and “demand” (Wallace & Rafols, 2015). In this paper, we empirically investigate how public research resources are mobilised to tackle a global and multidisciplinary problem such as avian influenza, with a focus on the institutions that govern (in a broad sense) research and shape outcomes.

This study seeks to link research contents with macro-scale science policy analysis (Laudel & Gläser, 2014). It also intends to bridge the gap between a more social constructivist scholarship that links value-laden framings and perceptions of risk (for example, of a pandemic) and benefits (e.g. of a vaccine) with research agendas (Jasanoff, 2004; Stirling, 2007b), and a more pragmatic science and innovation policy perspective that ultimately seeks to provide decision-making tools for effectively managing research. A novel methodological contribution of the article is the use of science overlay maps (Rafols et al., 2010) combined with qualitative interviews to illustrate institutional dynamics.

We first show that avian influenza research is a highly contested and politicized topic, dominated by persistent controversies associated with the risk of a pandemic. Most importantly, this contested arena manifests itself as a science policy debate, reflecting challenges at many levels in the way research funding is allocated and spent. We then demonstrate that, rather than being oriented to a given mission, priority-setting is shaped instead by institutional dynamics, particularly incentives arising from the pharmaceutical sector, or associated with public funding and publication pressures. These have a tendency to focus research on some narrow range of scholarship. On the other hand, while mandate-driven (governmental or intergovernmental) public organizations working on influenza also have their specific own research focus, their agendas are often perceived as more connected to health needs, and they may not have an impact on the overall landscape. The relatively small set of research foci, despite a wide range of perspectives and worldviews, suggest a lock-in of research into restricted topic areas, independently of whether or not these area are perceived by stakeholder as promising an "optimal" or cost-effective set of solutions. In the case of influenza, high levels of uncertainty and "contestedness" (or ambiguity) would advise to follow more diversified portfolios (Stirling, 2007a).

The article is organised as follows. In Section 2, we provide some background to the study, and present evidence, including through a cursory analysis of editorial content of scientific journals, showing avian influenza research as a fundamentally contested and uncertain field that has grown rapidly in response to recent outbreaks. In Section 3, we address this problem by introducing a mixed methods approach which combines interviews and scientometric mapping. In Section 4, we explore stakeholder perspectives on avian influenza research covering the following aspects: 1) views of societal demands, i.e., desirable outcomes of avian influenza research; 2) descriptions of the science supply, i.e., the research landscape; and 3) the main institutional drivers that have an effect in the shaping of research contents. Section 5 discusses the insights and implications for public research management.

2. Background: avian influenza as a case study

In this section, we provide an overview of the avian influenza problem from a science policy perspective. We argue that avian influenza is a particularly useful case study for understanding research prioritization in a contested field, based in part on the extensive literature which highlights some potential research issues and the role of key institutions in shaping policy. We show how this research area underwent a period of tremendous growth in funding worldwide, though dominated by a few major funding and performing research institutions. Over the last 10 years, avian influenza has been shaped by debates on different types of risk and uncertainty that are influential inside and outside the scientific community. This implies a need to consider avian influenza research in terms of a wide range of policy and diverse stakeholder interests (Hess, 2007, p. 22).

2.1 Global research and policy context of influenza

While all Influenza A strains can in theory be carried by birds, avian influenza usually refers to specific strains which are dominated by birds (as opposed to swine, for example). Furthermore, the bulk of research over the past ten years has tended to focus on highly-pathogenic strains of avian influenza, especially those which may be susceptible to cross-species transmission. In many arenas of policy and research, the term "avian influenza" itself is still closely linked to a perceived risk of the specific H5N1 strain (responsible for most outbreaks since 2003), although the recent emergence of new highly-pathogenic strains such as H7N9 has also become a serious concern. Overall, however, there is considerable overlap, both from a policy and research perspective, with other types of influenza.

Influenza is simultaneously a scientific, a political and a social object (Quinn, 2008). Historically, influenza has remained elusive to researchers, in large part because of the ability of the virus to mutate, to have varying levels of virulence to spread both through animals and humans. More successful preparedness measures or responses to epidemics tend to be multi-dimensional and recognize the variety of local conditions and concerns. Being a global problem, the overall response has been heavily influenced by three international organisations with a focus on human health (the World Health Organization), agriculture and livestock (the Food and Agriculture Organization) and animal health (the International Organization for Animal Health or OIE), under the aegis of a "coevolution" of science and policy (Chien, 2013).

Previous work by Ian Scoones and colleagues has revealed that the three distinct dominant narratives of control are focused on veterinary medicine, public health and pandemic preparedness (Scoones, 2010 Chapter 1). The existence of contending narratives is a source of significant tension in the development of health policy and research policy. This tension has led to the construction of new worldviews (and programs) such as "One Health", which sought to integrate the animal and human dimensions of influenza. Various framings of risk have arisen due to so-called "pandemic threats" or "emerging diseases", highlighting differences between global preparedness and control measures at the local level. Often, framings of the issue in response to a perceived risk can be characterized by assigning blame to or stigmatizing other (usually less powerful) groups (Abeysinghe & White, 2011; Barrett & Brown, 2008; Global Health Watch, 2011, pp. 146–153; King, 2002).

2.2 Trends in incidence, research funding and public debate

In this subsection, we focus on the interplay between incidence, mortality, research funding and science policy controversies. Without providing detailed temporal accounts of these elements, or seeking to provide causal relationships between then, we show that there is a clear research "response" to outbreaks (with a relatively short time lag), a competition for resources (e.g., between types of influenza), and an increase in science policy debates (linked to broader public health debates) following the growth in research. This sets the stage for our subsequent in-depth analysis of the avian influenza. It also points to future opportunities to dig deeper into research funding data, which is beyond the scope of the current study.

Table 1 summarizes the number of H5N1 cases and deaths reported since 2003, primarily in Southeast Asia, but also in other countries such as Turkey and Egypt. Another avian influenza strain, H7N9, has infected an estimated 453 people, killing 175 in 2013-14.[2] To provide some comparison, the 2009-2010 swine influenza pandemic (H1N1) killed at least 18,500 people, based on laboratory-confirmed tests, though the estimate of total deaths is much higher (up to 201,200) (Dawood et al., 2012). While developing countries have advanced, to varying degrees, approaches to tackle the outbreaks within their borders (Scoones, 2010, Chapters 3-6), developed countries have been primarily concerned with dangers of a global pandemic (Abeysinghe & White, 2011).

Table 1: Number of deaths and reported cases of H5N1 worldwide between 2003 and 2013[3]

Year	H5N1 – reported cases	H5N1 – deaths
2003	4	4
2004	46	32
2005	98	43

[2] October 2, 2014 WHO risk assessment from
http://www.who.int/influenza/human_animal_interface/influenza_h7n9/Risk_Assessment/en/

[3] November 2, 2017 data taken from the WHO at
http://www.who.int/influenza/human_animal_interface/H5N1_cumulative_table_archives/en/

2006	115	79
2007	88	58
2008	44	33
2009	73	32
2010	48	24
2011	62	34
2012	32	20
2013	39	25
2014	52	22
2015	145	42
2016	10	3

Figure 1 shows the funding profile for avian influenza as a "response" to this crisis, both in absolute dollars and as a proportion of influenza project funding. We show the figures only for NIH, which is the dominant public research funder worldwide (due to the availability of data. Evidence from other funders such as BBSRC in the UK point to similar trends[4]. Figure 2 shows the number of publications associated with Influenza A and avian influenza. US data point to a rapid increase in funds in 2006 and 2007, followed by a recent decline, which confirms recent reports from the UK that this was a period in which influenza research in general grew significantly, especially considering its "burden" relative to other diseases (Head et al., 2014). In terms of publications, while avian influenza dominated the influenza A research landscape prior to 2009, the emergence of the swine influenza pandemic shifted research priorities significantly.

Thus, beyond the increases in inputs and outputs, these patterns point to the need to understand how research systems—in particular, dominant institutions—responded to a large "shock" (and influx of funding) beginning in around 2004. Finally, the bibliometric data lends itself particularly well to examining an emerging research landscape linked to well-defined events such as pandemics, as we do in Section 4.2 below. A separate analysis (beyond the scope of the current paper) could look at these funding trends in much greater depth. Avian influenza, as an instance of a global outbreak, is a good case study for examining the narratives and the contexts that underpin the rapid growth in research on a global level, although we limit our interview-based qualitative work to Europe in order to be able to contrast the narratives of participants in similar research and policy contexts.

[4] The BBSRC, the "Gateway to Research" and the http://www.uberresearch.com databases were consulted between January 2016 and November 2017 at https://www.bbsrc.ac.uk/research/grants-search/advancedsearch/ and http://gtr.rcuk.ac.uk/ using the keywords "avian influenza" and "H5N1", and point to similar trends, though some data is only available after 2006 – it is therefore less informative and may be inaccurate to make the comparison between funding agencies.

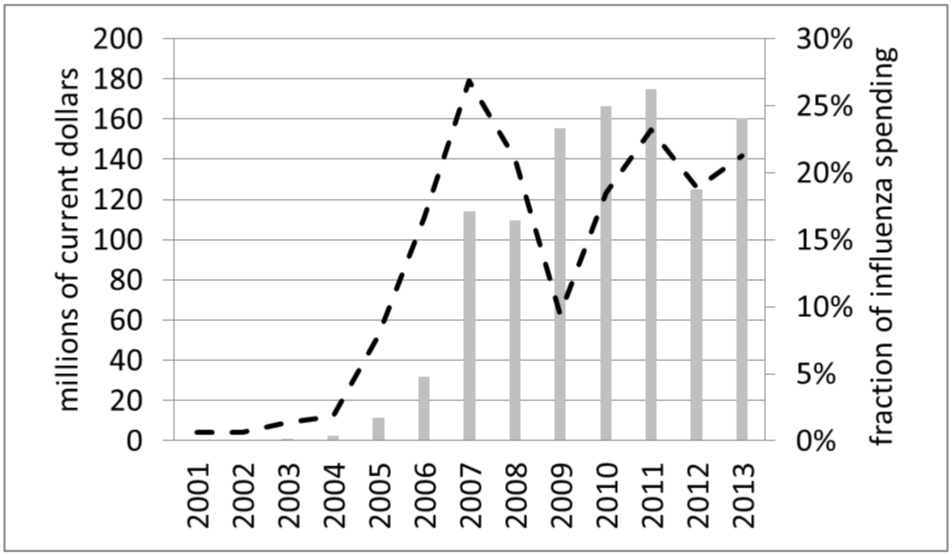

Figure 1. Vertical bars (left): NIH funding (in millions of dollars) for avian influenza, by fiscal year. Dotted line (right): avian funding expressed as a fraction of total spending on influenza, including H1N1.[5]

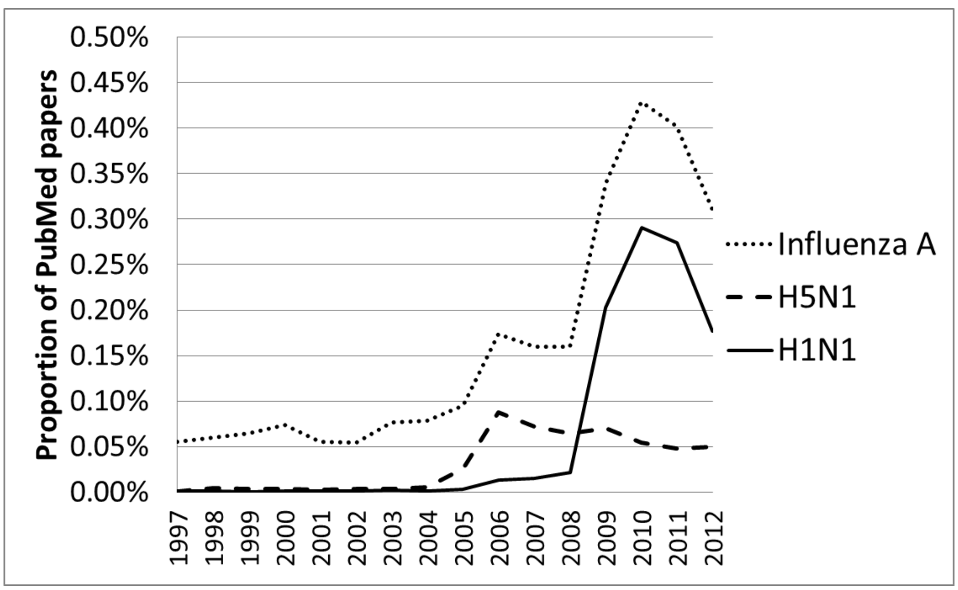

Figure 2. Number of papers published on two major strains of Influenza A. H5N1 is the strain most commonly associated with avian influenza and H1N1 with swine influenza.

A variety of science policy debates arise when there is a rapid increase in research on a contentious, high-profile issue. These debates can be in part captured through discussions in prominent scientific journals such as *Nature* or *Science* (Waaijer, van Bochove, & van Eck, 2011), which often signified issues with

[5] Data downloaded using NIH RePORTER tool (http://report.nih.gov/), June 2014, using keywords pertaining to influenza overall and strains typically associated with "avian influenza" (H5N1, H7N9, H7N7). Both project and sub-project funding is included.

significant research funding at stake. We performed a search for editorials related to avian influenza[6] in *Science, Nature, The Lancet, British Medical Journal, New England Journal of Medicine* and the *Proceedings of the National Academies of Science* and apply an ad hoc classification (acknowledging significant overlap) of the 84 editorials found. "Vaccine and treatment" refers to the pharmaceutical methods to mitigating risk (in particular, the debate over their effectiveness or equitable access); "characterization" refers to debates over the nature and origins of the disease; "dual-use research" refers to the risk associated with gain-of-function experiments for bioterrorism or inadvertent escape of the virus; "control" refers to debates over the most effective strategies for mitigating risk (on a national or global scale); and "pandemic risk" refers to the debate over estimating the risk of a global pandemic.

Figure 3 summarizes the evolution of these topics, indicating the waxing and waning of various debates, but a persistence of avian influenza research as a *contested* enterprise and a sense of *uncertainty* with regards to the intended and unintended impacts of research. Initial debates focused on defining risk, while later debates tended to focus on dangers of research (2012), or on characterization and control of new strains (2012-2013). Our examination of editorials points to a variety of sociotechnical framings of the research itself. While some of these themes are focused on the *uses* of research (e.g., vaccines and treatment), others pertain more to the *content* of research (e.g., the characterization or avian influenza) and a significant number of debates speak to both of *uses* and *contents*. Most often, the outcomes of the research and the research itself are interwoven in the same narratives, along with issues of governance.

In summary, the nature of avian influenza as a research object, and its funding profile, can be characterized by a rapid expansion of research amidst many competing public health policy narratives. The ensuing science policy controversies point to an engagement of policymakers, researchers and the public in defining (or seeking to define) the research agenda, possibly symptomatic of a widely perceived disconnect between research and desired outcomes, as many of our interviewees have framed the issue. Most importantly, the patterns found point to the interest of illuminating these perspectives through in-depth interviews and data analysis. We thus use these findings as a starting point to probe the research outcomes and research landscape in greater depth in Section 4.

[6] Here, we searched for the terms "avian flu", "avian influenza", "bird flu", H5N1 and H7N9 in these journals and restricted ourselves to the "editorial material" category of articles in Web of Knowledge.

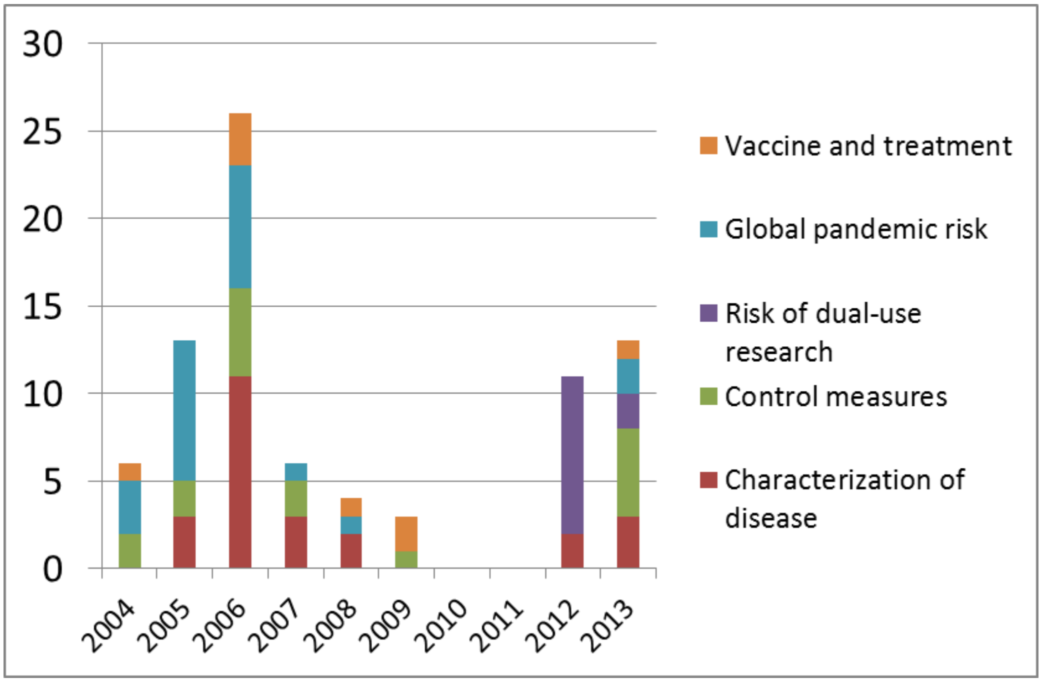

Figure 3: Number of editorials regarding avian influenza in leading scientific journals, manually assigned to five different categories. Note that years without bars mean that no editorials are found.

3. Methodology

Given that it is very problematic to generate or access reliable information on research and societal demands for a challenge such as avian flu, we have opted for a mixed methods approach. On the one hand, we relied on funding and publication data to describe research supply. On the other hand, we interviewed informed stakeholders, i.e. scientific experts and policy makers in order to a) characterise the landscape of research options, b) relate research options to societal outcomes of avian influenza research and make value judgments about research priorities and policy objectives. The approach assumes that stakeholders share some common understandings of the risks of avian influenza and the research options to mitigate it. More details of the methods are found in the Supplementary Materials file.

3.1 Semi-structured interviews

A series of semi-structured interviews were conducted in 2014 to gather a wide variety of perspectives from stakeholders. For this purpose, fourteen interviewees were asked to describe avian influenza research in terms of trends and structure, as well as expected outcomes and institutional drivers. The interviewees selected were at senior positions within organizations that were involved in avian influenza research as producers, users or otherwise influential actors regarding the direction of public research. The selection aimed to have candidates from various sectors and countries across Europe. Its goal is not to be a representative sample of stakeholders in the field, but to cover a broad spectrum of expert views. Participants included directors and policy advisors at funding organizations, regulatory agencies, NGOs and journals, as well as senior researchers based in a variety of organizations operating at the national and international levels. The expectation is that interviews can provide crucial insight, especially when supported by quantitative information, and in light of the current scholarly literature, into the range of views held by stakeholders on avian influenza.

As a starting point for seeking out patterns and characterizing responses, interviewees were classified based on their degree of technical knowledge of any area(s) scientific research related to avian influenza, as well as their degree of policy knowledge or influence, based on an assessment of the nature of their organizational affiliation (see Supplementary Materials). Figure 4 provides a sense of the level of diversity of interviewees, skewed towards individuals with high levels of expertise in the field. Researchers with world-class recognition in the field would have the highest levels of technical expertise, as opposed to "generalist" policymakers or advocates. On the other hand, "policy focus" in the vertical axis refers to how much effort an organization devotes to either science policy or health policy. Here, university researchers rank low, while government research agencies are slightly higher and advocate groups and policymakers at the national, European or international levels rank highest.

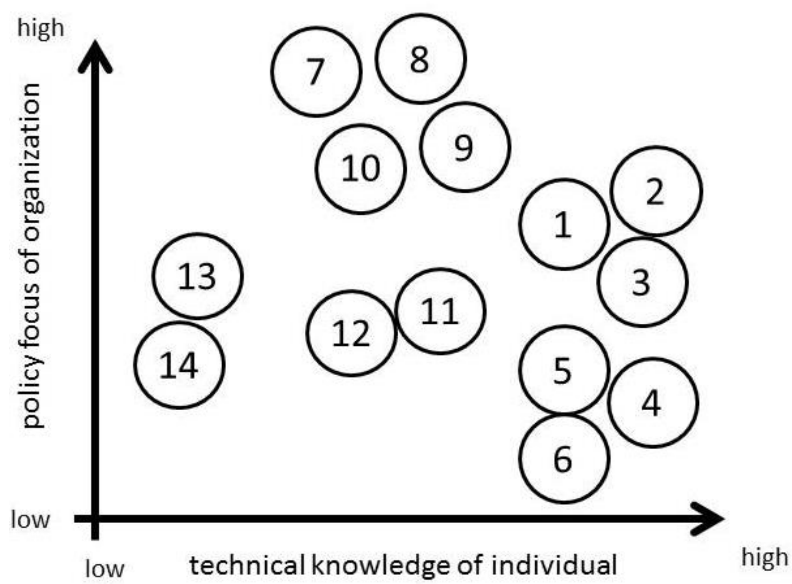

Figure 4. Schematic representation of the distribution of main stakeholders interviewed (arbitrarily assigned a number of 1 to 14) according to policy and technical expertise. This illustrates the level of diversity of the selected interviewees, which are nonetheless skewed towards relatively high levels of technical expertise.

Participants were asked about their views on various aspects of avian influenza research: what types of research options could be considered, which were prioritised, what obstacles or challenges they faced (see Supplementary Materials). The interviews were designed to characterize what *types of views* exist about this field of study and to suggest connections between the type of research conducted and its outcomes. We focused on extracting the context surrounding the account provided by interviewees, on seeking out instances of divergence or consensus among participants, as well as on institutional factors deemed important by researchers (Benner & Sandström, 2000; Goldfarb, 2008; Heinze et al., 2009; Laudel & Gläser, 2014). This approach is similar to the use of interviews in multi-criteria mapping and related methods to elicit normative appraisals and narratives through a relatively small number of in-depth interviews, and allows us to capture and probe a diversity of opinions in a contested space (Burgess et al., 2007).

We also focused on views of how avian influenza research and outcomes are related. To do so, we appraised participants' perspectives of the different desirable outcomes and the different research options for achieving them. We asked participants to discuss institutional factors that affect the interplay between content and outcomes through narratives that revealed both normative expectations as well as their personal experience in the field. This approach allowed us to capture framings associated with different types of avian influenza research, as well as the relationship between institutional drivers and research options, as perceived by participants.

3.2 Quantitative analysis of funding and publication data

Our analysis was supported by quantitative data on publications on avian influenza over the 2004-2013 period. The novelty in our methodology lies in defining a set of avian influenza publications, linking it to article-level data on funding, research organizations, and developing new mapping tools with this data. First, delineating a research topic with keywords is always difficult and potentially open to controversy. Therefore, we use the Medical Subject Headings (MeSH) of the PubMed system, which is perceived as a reliable classification method (Agarwal and Searls, 2009; Evans et al., 2014). Specifically, under the parent heading of 'Influenza A virus' in the MeSH category of 'Organisms', we selected specific strains (H5N1, H7N9, H7N7, H7N10), combined with articles tagged as "Influenza in Birds" under the separate parent heading of "Orthomyxoviridae infections". We then used an algorithm developed to retrieve the records in Web of Knowledge from the Pubmed records (Rotolo & Leydesdorff, 2015). This yielded 3935 papers between 2004 and 2013 (the 2013 results were only partial at the time of download). This approach is more accurate that searching for Avian Influenza in Web of Knowledge (WoS) titles, keywords or abstracts, as the PubMed system is a curated and well-defined taxonomy.

The corpus of articles thus obtained allowed us to study the research landscape associated with a given set of diseases, as well as to compare it with the research associated more broadly with Influenza A (which includes the H1N1 "swine flu" strain, as well as seasonal influenza strains). From the WoS titles, we are able to extract the funding information through the "acknowledgments" section of the article (Costas and Van Leeuwen, 2012), using the Vantage Point software package and manual data cleaning (see details in Supplementary methods). Similarly, we analyzed the addresses of authors, the impact factor of journals, their disciplines and sub-disciplines (as defined by WoS), in order to get a complete picture of the research landscape. There are limitations in using these parameters. Most importantly, funding data from acknowledgments is often incomplete, it includes "conflicts of interests" and is highly variable according to the practices of journals and fields. To a lesser degree, multiple affiliations and large numbers of authors means it is difficult to pinpoint where the research is done and by whom. Finally, the disciplines and sub-disciplines assigned to journals are imperfect (e.g., in the case of multidisciplinary journals) (Rafols and Leydesdorff, 2012). Nevertheless, these are bibliometric methods and data sources that are extensively used to analyze and assess research outputs and remain valid at the aggregate level.

In order to illustrate the variety and balance of topics and approaches associated with avian influenza, we focused on "mapping" the research landscape as a cognitive space – this is the space as defined by similarity of topics, methodologies, theories, disciplinary traditions and research objects. While this can be done through several methods such co-citation or bibliometric coupling analyses, we found that maps generated through the network of co-occurrence of terms within the abstracts using the VOSviewer software package, provided a fast and easy-to-use interface so as to identify clusters within the landscape (van Eck & Waltman, 2010; Waltman, Eck, & Noyons, 2009). We use mapping methods following the so-called overlay mapping technique, which allows to view the relative position of a publication subset in a larger context (Rafols, Porter & Leydesdorff, 2010). With “basemaps” formed by all avian influenza publications (n=3,935) between 2004 and 2013, we overlaid subsets of this dataset in order to visualize only the research associated with specific disciplines, affiliations and funders, as discussed above (see Supplementary Materials for more details). While this method has been shown to be useful to represent a research landscape, interpretation is required to understand the meaning of the maps by recognizing terms and patterns among terms.

4. Results: Perceptions of societal demands, research supply and the mediating role of institutions

Building on the characterization of avian influenza research above, in this section we present the two main results of this study. First, we show that there is a wide range of explicit characterizations of research outcomes and the research landscape. We later propose that this diversity can inform the deliberations around research prioritization. These are critical issues that speak to both fundamental perceptions of risk and our understanding of how multi- and transdisciplinary research is organized. Most importantly, we demonstrate the fundamentally uncertain and contested nature of this area of research. Second, we show how current institutional structures, particularly those relating to competitive grants, publishing pressures, and linkages with the private sector, systematically shape the type of research outcomes generated. While supporting a diversity of views on research options and outcomes is especially critical when the research agenda is uncertain and contested, the incentives of these institutions lead to a focus of research in certain topics and a questionable relative under-investment of research resources to certain topics or epistemic approaches.

4.1 Diverging views on desirable societal outcomes of research

This subsection explores the diversity of views on the desirable societal outcomes of research and the difficulties of linking them to research options. We seek to complement existing analysis how specific scientific responses to avian influenza are constructed and used (Leach & Scoones, 2013) by using the issue of research prioritization in general as a starting point, rather than specific health policy issues or research themes. We begin by describing the diversity of stakeholders’ perceptions of how the risk of an avian influenza pandemic can be mitigated by research. We show the range of problems that define this contested space, focusing on perceptions of risk and pathways to risk mitigation. The existing literature and the findings from analysis of editorials in section 2, together with the stakeholders’ perceptions described here, allows us to explicitly articulate the key issues that can inform deliberations about research prioritization. It also demonstrates that avian influenza is not simply a contested research space, but also a polarized one and a highly uncertain one.

4.1.1 Defining desirable societal outcomes

The policy responses to avian influenza—both through research and other measures—are conditioned by public responses and media narratives that have focused on risk. These have been well-documented in the existing literature, revealing how uncertainty and "catastrophe" are among the leitmotivs that dominate the discourse relating to the risk of a pandemic during outbreaks (Fung et al., 2011), as is indicated in Figure 3. Indeed, this same figure hints at a constant of editorials on "control", and interviews confirm that the outcomes of research are generally defined in terms of their ability to minimize risk related to pandemics, either through prevention or control.

It follows that avian flu is therefore one of many cases in which the imagined or desirable research outcomes depend on how risk and mitigation measures are conceived. Figure 5 illustrates the existence of diverse framings, heterogeneous perspectives and lack of consensus regarding these research outcomes. We notice that significant differences exist even within the same type or level of expertise of stakeholders (more details on the characteristics of interviewees are found in the Supplementary materials). We can summarize how views on research outcomes are influenced by perceptions of risk in three different ways: by views on level of uncertainty, on approaches to assessing risk, and on approaches to mitigating risk. The first is concerned with the likelihood a future epidemic. The second deals with a normative vision of risk assessment processes and whether the pandemic "threat" can be best addressed through formal and standardized mechanisms (generally by larger organizations) or through a more informal and subjective, procedure (generally in smaller field or lab-based settings). For example:

> *The zoonotic risk. Not in a formal way. […] In a, sort of, "God, this looks bloody dangerous," or "This one looks about the same as," such and such. […] It's a gamble. But, you know, what you're trying to do is you've got to have - you can't do it by sticking things into computer programs. It's sort of like a general feel for things that - I think it's a general feel (government researcher).*

The third distinguishes between addressing underlying socio-economic issues vs. technological "fixes" as distinct narratives (Scoones and Forster, 2010). In general, top-down approaches speak to technological solutions which are centrally deployed (internationally or by country), while bottom-up solutions are more often associated with solutions which focus on the local socio-economic and environmental conditions.

While there is general agreement on the need to "tackle" avian influenza or to "guard against" future epidemics, any steps towards these general outcomes were usually not framed via pathways fostered by specific research options. While many stakeholders shared a taxonomy of possible mitigation strategies as either antiviral drugs, vaccines or public health interventions, this taxonomy was subjective, not unanimous and does not lead to the articulation of specific research priorities (Ferguson et al., 2006). This includes, for example, whether we should focus on improving existing influenza vaccines or on developing new ones, and how this related to problems of access to, as well as distribution and production of vaccines (Fidler, 2010; Friede et al., 2011). In the case of non-technological pathways (e.g., focusing on primary care, socioeconomics or national surveillance) for addressing avian influenza, the gap between research options and identifiable outcomes of it often appears even wider.

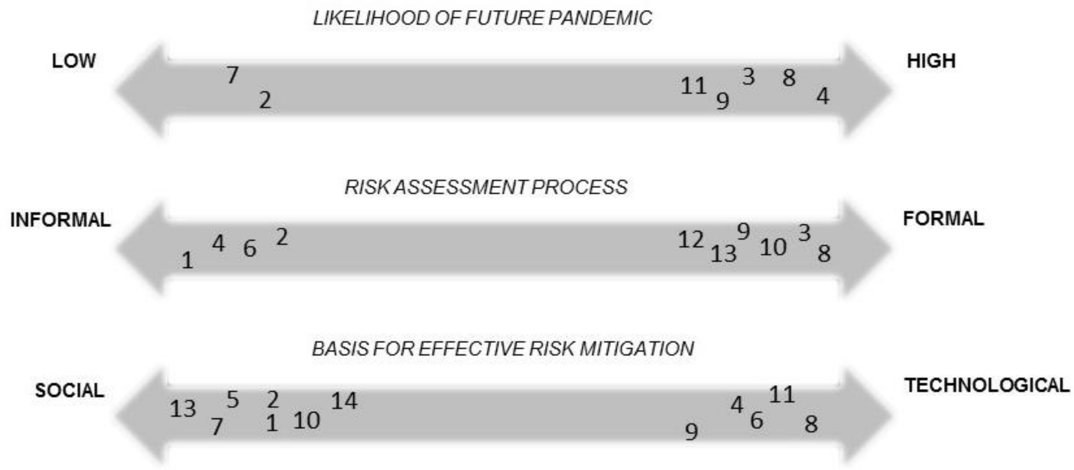

Figure 5. A schematic representation of the three axes according to which we describe perceptions of risk and risk mitigation. The numbers refer to individual interviewed stakeholders (see Figure 4). Note that many stakeholders did not express a specific preference along some of the axes, hence not all interviewees are represented. No significant correlation was found between interviewees' expertise (as represented in the two axes of Figure 4) and risk perceptions.

This divergence of views is further complicated by the fact that many experts recognize the possibility of adverse outcomes of research. In the case of avian influenza, the most well-known are dual-use research (potential intended misuse by some stakeholders), as well as unexpected safety risks for the general public. They are both associated with "gain-of-function" experiments, whereby viruses undergo directed mutations in a laboratory setting (for example, Herfst et al., 2012). Since 2011, this has been an object of intense technical, ethical and policy debate (see 'Risk of dual research' in Figure 3), with significant implications for the governance of research (Edwards, Revill, & Bezuidenhout, 2014; Suk, Bartels, Broberg, Struelens, & Ozin, 2014). Others hinted at control measures arising from flu research that might have an unacceptably adverse effect on livelihoods. Overall, the narratives put forth by stakeholders point to a plurality of fundamentally different views on risk and its management or mitigation, that are not attributable to the well-documented conceptual and institutional gaps between scientists and policymakers, or between how the public and "experts" perceive risk.

Setting research agendas for a wide topic such as avian influenza is not a centralized process that aims to achieve an "ideal" distribution of research options and outcomes, not least because priority setting happens across a range of countries and agencies and at multiple levels. Rather, the de facto priorities observed represent the result of a variety of efforts by stakeholders that exert varying degrees of influence over the directions of research. Indeed, our interviews confirmed the importance of, and wide-ranging views about, *where* decisions on funding or policies on incentives are made. In particular some interviewees had concerns over whether influenza research funding is an area where a diversity of stakeholders can or should participate in decision-making.

In summary, building on existing literature and linking science to risk perceptions (particularly those found to be associated with influenza), we characterized participants' views about desirable research outcomes by categorizing their responses in terms of likelihood of pandemic, formal vs. informal risk assessments, and social vs. technological approaches to risk mitigation. This paints a picture of fundamental uncertainty and disagreement associated with the research object itself and the ultimate uses of research. In addition, it indicates that the divergences cannot simply be "reconciled", but rather than they should be utilized to inform broad deliberations about the research to capture the wide range of perspectives about avian influenza. In the following section we move from the analysis of expected outcomes and uses of research, to the analysis of research options within scientific community.

4.1.2 Characterizing the avian influenza research landscape

Interviews also revealed an unexpected diversity of perspectives regarding *possible* research areas of themes associated with avian influenza. This divergence of understandings is also borne out by an analysis of publications. Moreover, as we explain in this section, not only is the division of research into epistemic categories (distinct bodies of knowledge) ambiguous, but there are inherently divergent ontologies as to what constitute "promising" areas of research and several ways in which the set of research options are inherently polarized. Avian influenza is thus a case where deliberations regarding agenda-setting are important because of contrasting perspectives, but where implementing participatory processes of prioritization can also be challenging because of lack of shared epistemic ontologies.

Even though disciplinary norms and perspectives are well-entrenched in the scientific communities and thus remain dominant, many societal challenges are increasingly viewed as requiring multi- or inter-disciplinary approaches. This means that the knowledge base for societal challenges can be expected to draw upon various disciplinary areas. Therefore, the integration of a broad spectrum of cognitive perspectives is often cited as a desirable to tackle "complex problems" such as avian influenza (Rosenfield, 1992). Stakeholders interviewed generally agreed that there is a need for diverse research avenues that transcend traditional disciplinary divisions.

To illustrate this diversity, we develop a semantic map of avian influenza research (Figure 6) based on co-occurrence of terms found in abstracts of scientific articles between 2004 and 2013 using the VOSViewer freeware.[7] The spread of vocabulary over the map provides us with a sense of what type of methods and objects dominate a given area of research (see caption of Figure 6). The clusters are relatively robust (i.e., changing the number of terms included in the analysis, or the thresholds for relevance has little impact), but their interpretation on the basis of the terms used is challenging. As shown in Figure 7, such clusters cannot be easily characterized with conventional disciplinary labels (based on journals' classification) due in part to the fact that influenza's research objects and methodologies are not specific to a single discipline.

Both the identification of the main fields and the language used to describe these fields varied widely among participants, but most found these maps to be a useful way of conceptualizing the field, whereby they could recognize trends, areas of research, and linkages across these areas. Certain areas of research were found to be associated with extremely different types of solutions and pathways to solutions discussed in the previous section. For example, some viewed animal research as primarily focused on understanding the socio-economic conditions for zoonosis (related to prevention), while others associated it mainly a fundamental biological understanding of transmission (related to preparedness).

[7] http://www.vosviewer.com/

Similarly, some associated epidemiological modelling with means for understanding the disease at early stages, while others viewed it as a source of policy recommendations for controlling outbreaks.

Furthermore, we observed that interviewees associated labels of research areas (which in principle are "objective") with judgments regarding the utility or the rigour associated with them. For example, that which is closely associated with public health or tracking epidemics was criticized by some as "soft", more "routine" or lacking analytical rigour, whereas research associated with the virus or immune response was described by others as "detached" from the main problems or as "too expensive" for what it yields. As such, some public research in a given area such as immunology was sometimes described as either over-funded in relation to the insights gained, while other research areas such as animal-based epidemiology were sometimes seen as under-funded. Modelling in virology, as in epidemiology, for example, was an area of particular contention, as described by a scientist working primarily in a policy arena:

> *There's a lot of research going on in modeling. ... But I always put some question marks. It's often difficult to model reality. There are too many unknowns and uncertainties. The danger is if you present a policymaker with a nice model with curves moving round and things, they tend to kind of adhere to it like, "Oh, great. This is kind of a solution for me."*

Participants did not view individual research areas as separate alternative options for tackling influenza research, preferring to consider various combinations of disparate fields of research. Indeed, research portfolios of programmes or organisations are thus characterized by varying proportions of resources being devoted to different *types* of research.

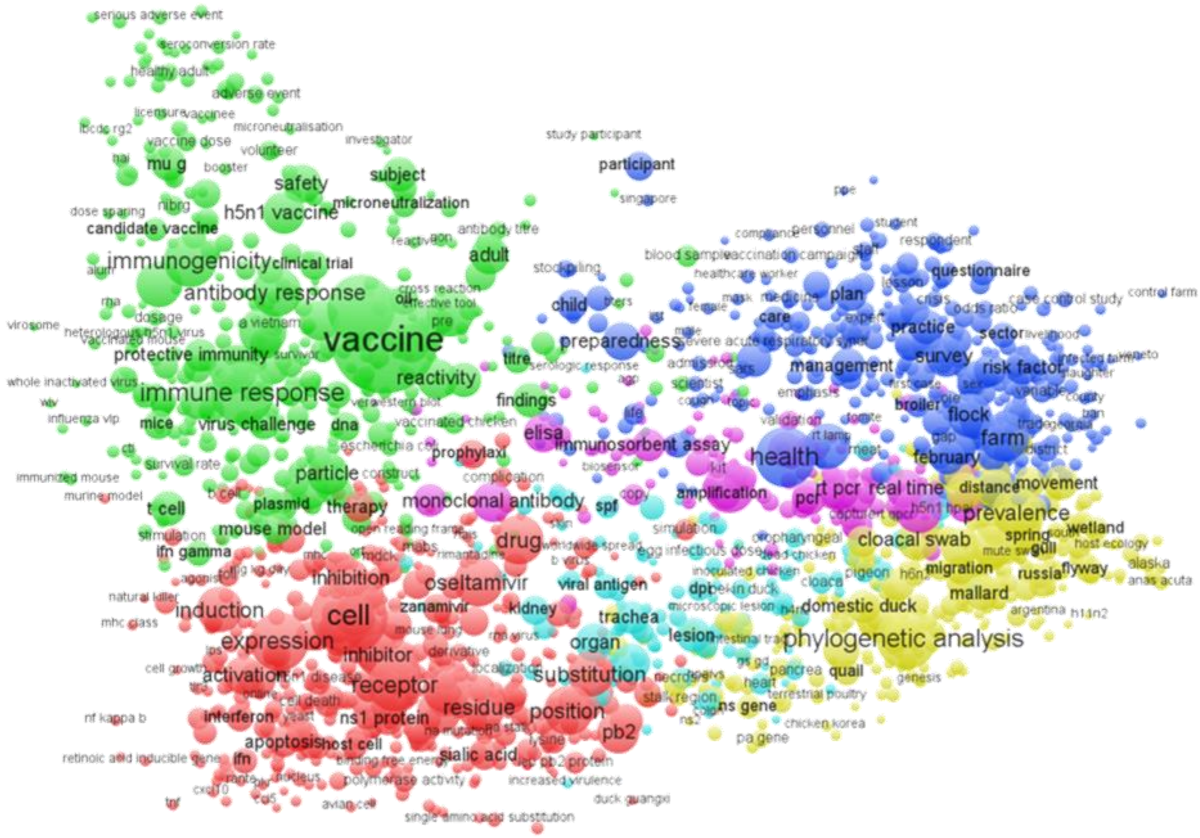

Figure 6. Map of the research landscape of avian influenza. The colours denote clusters found through VOSViewer's clustering algorithm, while the proximity denotes the level of co-occurrence of the terms (more details are found in the Supplementary materials). Based on the terms alone, the top left (green) corresponds to work related to vaccine development and understanding the immune system; the bottom left (red) focuses on the virological processes and on drug development; the top right (blue) is related to epidemiology and pandemic preparedness; the bottom right (yellow) on characterizing the virus origins and spread; and clusters in the middle are related to detection and diagnosis. Specific divisions therein, such as those identified in purple and light blue, could be associated with methodologies related to testing and pathology, respectively.

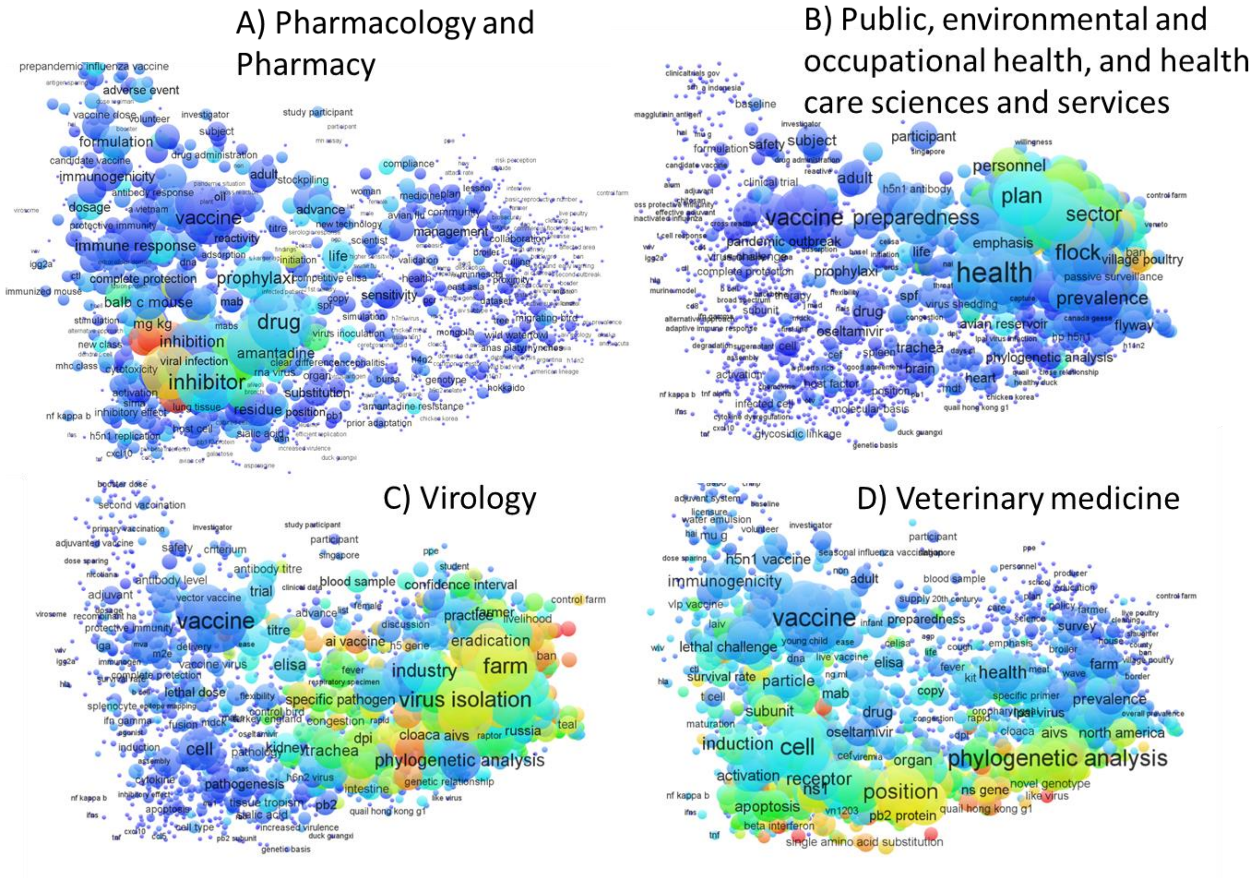

Figure 7. "Heat map" overlay of Figure 6 highlighting the relative frequency (size) and concentration (colour) of different terms for a given subdisciplinary set. The position of terms is kept according to Figure 6: the top left corresponds vaccine development and immunology; the bottom left to virology and drug development; the top right to epidemiology and pandemic preparedness; the bottom right to characterizing the virus origins and spread. Absolute frequency is shown by the size of the bubble of a term. The concentration (proportion of term that falls within a given category) decreases from red (most concentrated) to yellow (concentrated) to blue (less concentrated). It shows the prevalence of terms within the areas associated with specific subdisciplines (Web of Knowledge subject categories), indicated via the four labels. This map allows a visual representation of where publication in different areas occur in the research landscape and where they are concentrated, using a fixed framework that renders the different maps directly comparable.

There are several important "worldviews" of the research landscape that emerge from both the qualitative and quantitative analyses. Whether heavily involved in the research enterprise or viewing it from a users' perspective, stakeholders usually described avian influenza research overall in terms of two (sometimes three) major, but diverging epistemic approaches. Often such dichotomies are associated with implicit or explicit judgments (i.e., one approach is seen as "more desirable" than the other). Participants divided the overall research landscape in one of four different ways: 1) basic vs. applied research; 2) laboratory vs. field research; 3) animal vs. human-oriented research; and 4) laboratory vs. clinical research. Indeed, if we examine Figure 6 in closer detail, the map can be divided in two parts along any of these lines. Thus, the human/animal distinction is approximately between left and right, while the laboratory/field distinction is approximately between bottom-left and top-right. The basic vs. applied distinction was often cited as being between top and bottom, although most interviewees did not expand on this dichotomy in characterizing the landscape. For those with sufficient technical knowledge, however, disciplinary distinctions were more significant and often linked to this polarization of the landscape, albeit with very "blurry" boundaries. These multiple "polarities" are linked with normative judgments by stakeholders about which type of research should be pursued. Indeed, the research gaps that stakeholders identified in research are directly related to how they viewed different fields in terms of being more related or similar to each other, or how they saw the scientific community separated in two camps at the national or international level.

In summary, the analysis of the research landscape has highlighted a diversity of perspectives about avian influenza research, from the research itself to the outcomes linked to pandemic risk. The lack of shared understandings on several levels is perhaps expected for such a complex, contested and transdisciplinary topic. What is perhaps more surprising is the diversity of understandings and ontologies about the characterization of the field. One may wonder whether in these cases in which a shared vision is lacking, debates become more polarized and discussion on explicit research prioritization are inhibited.

4.2 Institutional pressures driving research agendas

In this section, we shed light on how institutions associated with the research system shape the type of scientific knowledge produced and, indirectly, also how this knowledge is used to inform decision-making. These institutions condition the choices made by researchers and they influence as well as those made by policymakers in setting research agendas on different organizational, national or international scales. Our observations suggest that these institutions tend to foster the concentration of research resources on a relatively small range of research options rather than fostering diversification, as might be more desirable in the face of uncertain and contested research outcomes and options.

Three types of institutional pressures were identified from the interviews of stakeholders: financial incentives from the private sector, rewards in the academic system (including both funding and publishing), and explicit sectoral missions of national or international science-based organizations (such as FAO, WHO, CDC etc.). Each interviewee's perception of the influence of these pressures (framed in the interview as deviating from an "ideal" research landscape) was ranked approximately as low, medium, high or not addressed (see Table 2), based on a codification of their responses, and associated either with research in general or with specific areas such as epidemiology or vaccine development. Table 2 provides another indication of the diversity of viewpoints that were investigated. This table is also a starting point for interpreting specific (and often value-laden) narratives from the interviewees as well as relevant bibliometric data, which are explored in the following sub-sections. Overall, the narratives and the bibliometric data suggest strong effects of the pharmaceutical sector and academic reward systems on the research landscape, while it is more difficult to generalize regarding the diverse impacts of missions of research-performing organizations.

Table 1: Number of interviewees (out of 14) expressing various levels of influence from categories of institutions on research, framed as a "deviation" from an ideal research landscape. Note that in many cases, the influence was associated with a specific area of research (e.g., vaccine development), rather than the landscape overall. This is particularly the case for those citing the impacts of the pharmaceutical industry and specific organizational missions.

Institution		High influence	Medium influence	Low influence	Not specified
Pharmaceutical industry		6	4	3	1
Academic reward system	Scholarly publishing	6	3	1	4
	Funding incentives	4	4	2	4
Organisational missions		5	4	0	5

4.2.1 Private sector influence: financial incentives

The private sector, primarily through the development of vaccines and antiviral drugs, plays a key role in avian influenza research, including that which is led by the public sector. For example, there are strong incentives to engage in public-private partnerships or to supplement public with private funding, across a range of areas of influenza funding. This is manifest in how research policies (e.g., calls for proposals) are set by public entities, for example. As might be expected, there is some polarisation on this issue in terms of the positive or negative role of the pharmaceutical sector. Many participants viewed this industry as driving innovation and as the main pathway to mitigating the risk of a pandemic outbreak. The majority felt that the private sector was significantly affecting key aspects of the public research enterprise (high/medium influence in Table 2), such as the ability to explore a wide range of interventions through "upstream" laboratory work. This view does not appear to be correlated with technical or policy "expertise", but rather with an interviewee's values or the stated missions of their respective organizations. Many participants also felt that the focus of the pharmaceutical industry, with a need to ensure good financial returns, is too narrow and that this may have constraining effects on the breadth of study areas considered by public researchers. For example, some interviewees questioned the industry focus on antivirals, since one-time vaccines usually have the potential to generate less revenue than antivirals in the case of an epidemic, but they may in fact have a stronger impact on mortality and infection (Ferguson et al., 2006).

Figure 8 illustrates where the focus of private sector support lies in the overall research landscape. It shows that articles acknowledging funding from pharmaceutical companies (but produced largely by universities) tend to focus on vaccines and antivirals (even more than other types of biomedical research). The fact that this is research conducted mainly by universities and hospitals, combined with the significant proportion of pharmaceutical funding over total influenza R&D expenditure, suggests that pharma's research agenda may have a significant influence on public research agendas.

This potential focus on vaccines and antivirals, and thus the lack of diversity of research options stand in contrast to the multitude of perspectives on how to address risk and risk mitigation described previously. This observation of a narrow focus support the hypothesis of a "lock-in" of solutions based on revenue-generating pharmaceutical approaches, precluding a diversity of options implicit in the broader sociotechnical debates (Stirling, 2007a). There are parallels to draw with the case of malaria, where funding has disproportionately gone to pharmaceutical interventions, whereas there is evidence that non-medical interventions have turned up to be more effective (e.g., Goodman & Mills, 1999). Specifically, the focus on certain pharmaceutical solutions tends to inhibit focused efforts on other interventions (e.g., border control, public hygiene, surveillance) or vaccine-based pathways that have important financial implications but cannot be viewed from a "market" lens (Gostin, 2006). One researcher engaged in systematic reviews and policy debates summarized the situation as follows:

> *Now, very few studies, by the way, are being done in the last 20 years to look at trying to answer that question [what causes acute respiratory illnesses]. And this will not surprise you because there is very little money in these studies because they might turn up answers that you do not want.*

Overall, we found in the interviews that perceived influence from the pharmaceutical industry in avian influenza research has increased tensions within the community of researchers and policymakers (especially regulators). It has had an indirect impact on public science through the potential for conflicts of interest faced by researchers in such a highly politicized field, be it due to these conflicts affecting the conduct of public science or due to the barriers against them which prevent effective inter-sectoral collaborations and access to private sector funding (Gulbrandsen & Smeby, 2005). The recent controversy over the effectiveness of the influenza antiviral Tamiflu and the availability of data from clinical trials has further exacerbated tensions between some researchers (Payne, 2012)[8]. Furthermore, the influence of industry over the research landscape extends not only to the pharmaceutical vs. non-pharmaceutical approaches, but also to choices of different pharmaceutical pathways to mitigate the risk of a pandemic. For these reasons, the effect of the pharmaceutical industry on the overall public research landscape can be characterised as strong, both in terms of driving research to its own agendas and also in terms of polarizing the perceptions of researchers and stakeholders. Naturally, this effect does not imply that this is somehow the "wrong" path to take in research, but it speak to the pervasiveness and impact of the framing put forth by the private sector in this case. Discussions of the pharmaceutical industry in particular also elicited comments by many interviewees to the effect that a more diverse distribution of resources might be more likely to contribute to solutions.

[8] For more details on the correspondence between various parties, see: http://www.bmj.com/tamiflu/roche.

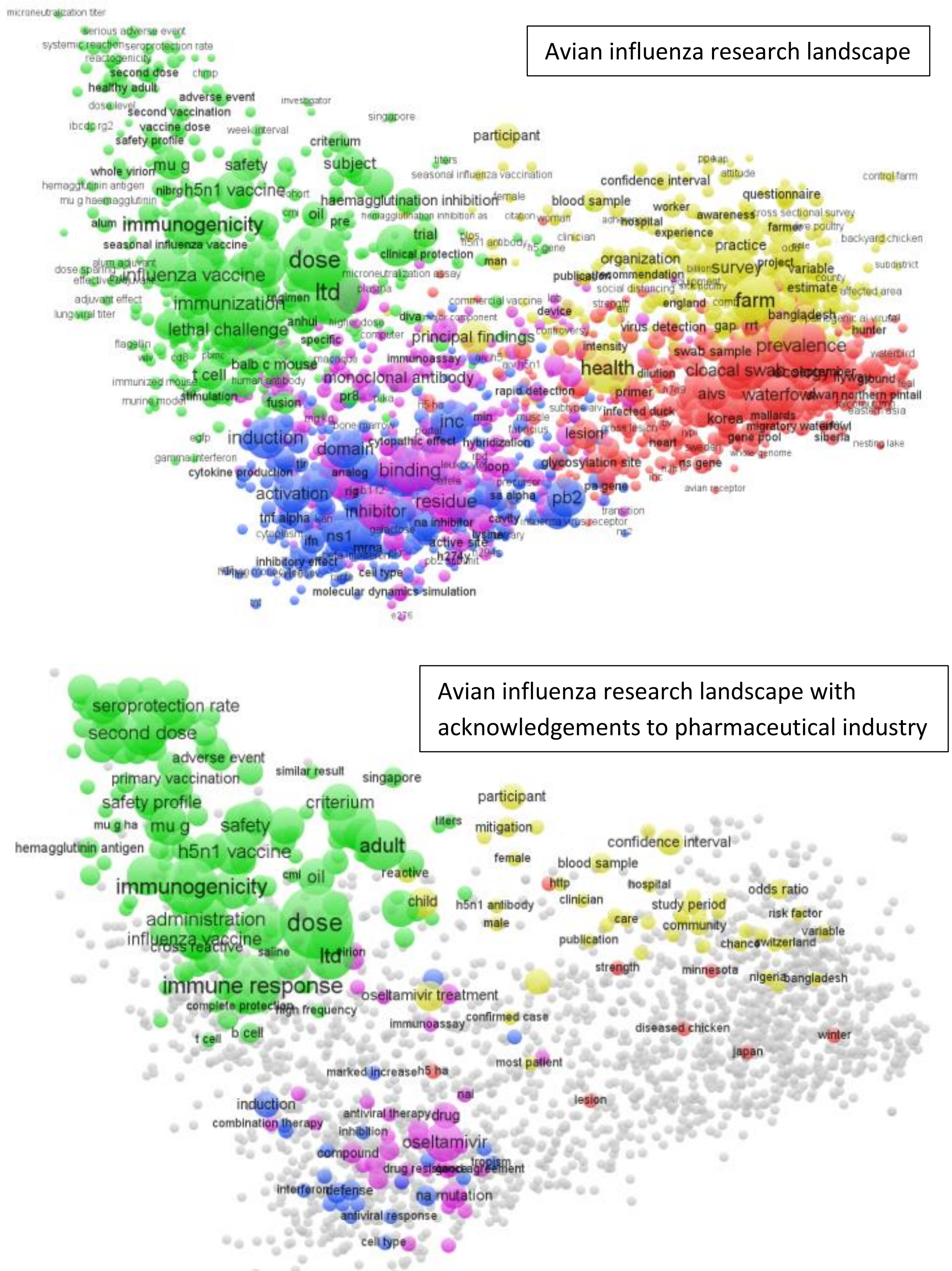

Figure 8. Top: Entire avian influenza research landscape (2009-13). This period is selected based on the availability of funding acknowledgment data from Web of Knowledge. Research areas similar to those in the 2004-13 map Figure 6 are observed (clockwise, from top left, we find clusters related to vaccine development, epidemiology, veterinary science and virology). Bottom: Overlay restricting terms to those appearing in articles acknowledging funding from the four most prevalent pharmaceutical companies: GlaxoSmithKline, Hoffmann - La Roche, Novartis and Sanofi Pasteur. The figure does not account for levels of funding, but simply the existence of publications that acknowledge funding and conflicts of interest.

4.2.2 The academic reward system: funding and publishing

Most participants believed that decisions regarding the allocation of funding and regarding publication of results played an important role in shaping avian influenza research. Grants and publications are the two main "currencies" of academic research and how they are incentivised has an important impact on the research enterprise itself (Butler, 2003; de Rijcke et al., 2016). Most participants negatively viewed these pressures, since certain fields of research being favoured over others in terms of funding and reputation. We separated the analysis in terms of the reward mechanisms into two systems: the public funding system and the publishing system.

For scientists, obtaining external research funding is not only a means for acquiring research resources, but also a means to gain reputation that is part of the performance assessment, even though it is not necessarily a good gauge of quality (Laudel, 2005). A recent (perceived) drop in funding for avian influenza (see Figure 2) was raised by several interviewees as having exacerbated the competition for resources. Some participants explained that funding schemes favoured fields such as virology and immunology that are perceived as more prestigious by policymakers and senior managers. The built-in preferences in these "excellence" schemes can thus lead to what many stakeholders view as "biases" in resource allocation (Shibayama & Baba, 2015). In a sense, the narrative of "excellence", both on a national or international level, supplants some of the discussion of research as a social need (Bozeman & Sarewitz, 2011). Furthermore, research funding is seen to favour projects which are deemed "innovative" or "ground-breaking", rather than some of the more routine work associated with efforts aimed at tackling disease (see Yaqub & Nightingale, 2012, on the polio vaccine). According to one participant:

> *For me, the operational research is much more what translates into how to manage the disease, how to translate it into policies. What I see is that research institutions and most of the research funding goes into much more this more fundamental research, looking at the virus, looking at the production of the vaccine. There's not much funding looking more to the operational side.* (senior scientist and advisor at an international organization)

More generally, interviewees saw funding mechanisms as being outside their sphere of influence, yet as a determining factor for how research options are not only promoted, but also defined. At the very least, this points to a lack of transparency in terms of what types of projects are being funded, or potentially to a lack of stakeholders' engagement in setting priorities (Tallon, Chard, & Dieppe, 2000).

Scholarly journals play a complex role in promoting, diffusing and, perhaps most importantly, rewarding various strands of avian influenza research. Many participants recognized that an *a priori* vision of the research landscape (such as the basis for the maps presented in Figures 6-9) are inherently skewed to reflect only research that is published in scholarly journals, thus excluding grey literature as well as correspondence or scientific advice to government that may or may not be made public. Pressure to publish is also perceived to have subtler effects in terms of the priorities of researchers.

> *You have certain articles that have been published, but the translation [to application or policy] of that is missing. Or for example, one of my big criticisms to many research projects, they go to villages. They do research in remote areas. But never this information is fed back to the villages themselves. You know? They are kind of so fixed to get it*

published, but the community where the research was done never has any benefits of that research.

Both science policy scholars and researchers indicated—albeit in different terms—that journals contribute to shape the overall balance of power between disciplines and among different specialties within the same discipline. In many cases these differences in power "distort" the research enterprise, pushing it towards certain areas (van Eck, Waltman, van Raan, Klautz, & Peul, 2013; Young, Ioannidis, & Al-Ubaydli, 2008). For example, standards on sample sizes and statistical tests have a significant impact on fields such as epidemiology, defining what can be published and where. Additionally, the waxing and waning in popularity of different techniques for developing vaccines (e.g., the use of adjuvants), particularly where there are high-profile successes or failures reported (Miller et al., 2013; Reed, Bertholet, Coler, & Friede, 2009; Shoenfeld & Agmon-Levin, 2011), can have a very fast and significant impact on what can and cannot be published in journals seen as prestigious.

Most importantly, this perceived "distortion" is related to the journal hierarchy in science, which is also connected to the reward system for science in the form of increased chances of research funding for authors publishing in high-impact journals. Those closely connected to research recounted specific examples of certain scientific practices being more recognized than others. For example, Figure 9 below shows the epistemic areas that a set of so-called "high-impact" journals cover most. Notice that the chosen subset (*Nature, Science, PNAS, Cell, BMJ and The Lancet*) includes multidisciplinary, biomedical and medical journals. However, Figure 9 clearly shows that publications in these journals fall mainly in the biomedical areas, particularly virology (bottom left region of maps) – and underrepresent field studies and epidemiology and public health (right regions of the maps), among others. Indeed, the ability of an article to receive high numbers of citations is larger in certain fields than in others (e.g., comparing biomedicine with social science). For example, according to one researcher:

Well, it's certainly something published new in a high impact journal, like you see some of them here that are considered high impact. So, something appealing there on influenza, yeah, you would immediately have people that try to mimic - to repeat it or to maybe twist the research line in that direction.

The case of perceived risks from dual-use research illustrates the various levels on which publishing pressures can operate. In this case, participants cited both a positive and negative impact of the controversy over dual-use research on publishing results from these lines of research (Edwards, Revill & Bezuidenhout, 2014). While existing or potential publishing restrictions may have discouraged some researchers from pursuing these lines of research, the visibility (as measured both by citations and other metrics such as tweets) received by those studies may also have made them attractive to top journals. Many participants suggest that academic incentive structures may have the most significant impact on narrowing the range of research avenues being actively explored with public funds. Although this effect appears to stem from localized decisions and interactions (e.g., at the level of a research organization, or a given journal), overall, the interviews and the bibliometric mapping point to a widespread and extensive impact of these pressures on the research landscape.

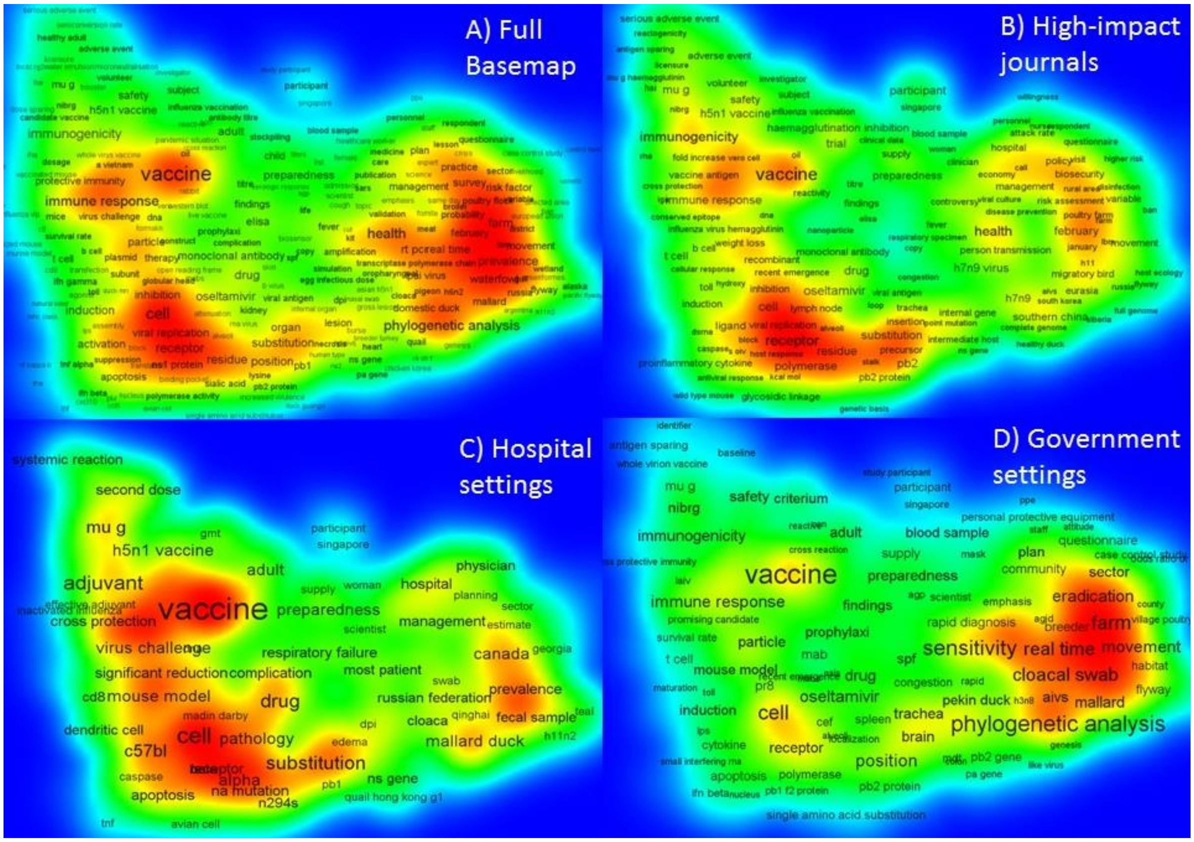

Figure 9: Publication density map of the avian influenza research landscape (2004-2013), showing which terms occur most often (in red) and which terms occur less often (in green). A) The same original "full basemap" of Figure 6 (without the coloured clusters, using instead a density visualization) showing where the bulk of publications lie: the top left corresponds vaccine development and immunology; the bottom left to virology and drug development; the top right to epidemiology and pandemic preparedness; the bottom right to characterizing the virus origins and spread. B) Subset of records in highest-impact journals (specifically, we have chosen Nature, Lancet, Science, British Medical Journal, Cell and the Proceedings of the National Academy of Sciences of the USA). C) Subset of research performed in hospital settings. D) research in government settings. The articles for hospital settings were selected by isolating authors' abbreviated addresses (in Web of Knowledge format) containing the strings "hosp" or "clin" (for hospitals), and "minist", "natl" or "agcy" (for government). Those containing elements of both sets, or containing the string "univ", were excluded to improve contrast.

4.2.3 Governmental and international research-performing organizations: mandates for missions

Avian influenza research takes place in a variety of settings associated with the different approaches (statistical analysis and modelling, "wet" biomedical laboratories, veterinary fieldwork, etc.), as well organizational contexts (government, private sector, non-governmental organization, or university). Naturally, scientific priorities vary among research performing organizations given their very different missions: regulation, communicating risk, informing national health policy, informing clinical practice or simply producing "excellent" science.

This subsection explores how the mandates of research-performing organisations have an effect on the research agendas pursued by researchers. We found that participants were often able to speak of "organizational pressures" on research in a general manner and, more importantly, relate their own organizational context to their roles as performers, funders or users of avian influenza research. Many participants pitted organizational pressures against stronger ones related to publishing or academic funding. For example, according to a scientist at a national health agency:

Yes, more funding [for this type of research is needed] because these are routine surveillance activities. These are not research. It's different because I need more money to have people working in routine surveillance activity in order to let me work on the research activity, publications.

Common narratives of interviewees associated these research-performing organizations with science done “on the ground”, “in the field” or even “on the frontlines”, referring to research that is not only driven by organizational missions, but is also more operational, targeted and restricted in terms of topics explored. Often both research and “related science activities” (Godin, 2001) are done in these contexts, which can be referred to as not just mission-oriented science, but “mandated science” (Salter et al., 1988). The latter is often associated with regulatory science, the “integration” (so varying degrees of science and policy) and a lack of control by scientists over the agenda and timing of their work. It is an institutional arrangement that is also generally less associated with disciplinary work.

Through our interviews, we identified two main categories of organizational pressures associated with “mandated” avian influenza research: informing policy, regulation and legislation (namely, national or international regulation, prevention or coordination endeavours) and informing clinical applications. These drivers can be associated with government, international organizations such as the WHO and the FAO, as well as hospitals and other health-oriented organizations. As a result of these ‘mandates’ the research these organisations perform tends to be targeted to policy-oriented or specific clinical applications. These areas of focus are illustrated in Figure 9, where we show that, for hospitals and governments,[9] the concentration of publications does not correlate with high-impact journals or even specific disciplines. Instead publications are focused on several distinct areas of the research landscape that are commensurate with the priorities one might expect from governments (control and surveillance measures) and hospitals (pathology, vaccine development and virology). In other words, there is a clear link between their ‘mandate’ and the nature of the research.

Many participants highlighted that the disproportionate influence of international organizations such as the WHO in driving both control policies and research policies meant that there was too much focus on human health, for example (as opposed to animals or livelihoods) and as a consequence less diversity in research. This has already been documented in terms of the dominant role of the WHO at the centre not only of international response narratives, but also research priorities (Scoones, 2010, Chapter 1). Other stakeholders highlighted the fact that disparate organizational missions hinder collaboration and sharing of information, which is central to tackling a complex issue such as avian influenza. For example, people working in hospitals or in the field are sometimes less interested in collecting high-quality samples that can then be used in a laboratory setting. Similarly, those working for national governments may be reluctant to share information or even virus samples. This reluctance can be because data at a national level can point to deficiencies in preparedness and prevention, or because there is concern over their

[9] Unlike in the case of analyzing funding from pharmaceutical companies, we focus here on the affiliations of authors. This poses certain challenges related to multiple affiliations, or to co-authorships between members of different types of organizations, which makes it more difficult to isolate a specific type of organization. With these caveats in mind, it was found that limiting affiliations to only hospitals, only governments and only universities appeared to be the most robust way of observing any patterns through mapping.

access or ability to use downstream outputs, such as vaccine use or production, in was the case in Indonesia (Fidler, 2010). The concentration of power (either in political or technical form) in some specific organisations can be problematic as it may reduce diversity both in control/policy measures and in research.

Unlike the funding private-industry and academic reward incentives discussed above, which are more diffuse, our exploration of these organizations explores organizational settings of the production of knowledge. These settings are extremely diverse, as is the power the organizations yield over policy or science agendas at various scales. The partial insights gained from interviews and the exploratory bibliometric data gathered do not point to a systematic impact of mandate-driven organisations on the research landscape. Rather, digging into the narratives that underpin the summary data in Table 2, we find that each individual mandate-drive organizations has its own set of dynamics and the priorities, which tend to be relatively localized, according to interviewees (see Table 2). There organizational do not create pervasive incentive structures the same way funders to, and, aside from dominant international organizations like the WHO, rarely dominate overall research paradigms. In addition, there is some evidence that mandate-driven organizations are often more connected to specific societal outcomes (as discussed earlier in this section), even if they also has its own narrow focus to a smaller subset of research questions.

5. Discussion and conclusion

This paper presented an empirical investigation of the dynamics and diverse framings of avian influenza research from a macro-level perspective, complementing studies that have focused on specific policy debates or research avenues (e.g., Scoones 2010). Through a mixed-method analysis that triangulated evidence from interviews, bibliometrics, funding statistics and literature, we first demonstrated how avian influenza is fundamentally contested and uncertain, both in terms of the research contents and its uses for risk mitigation. Second, we showed that both formal and informal institutional drivers, mediated through incentive structures for researchers, dominate research agendas: pharmaceutical industry priorities, publishing and public research funding pressures, and the mandates of science-based policy or public health organizations. Whereas private sector priorities and academic (publishing and funding) pressures are perceived to strongly shape overall research landscapes, there is no evidence that explicit priorities from many research organizations have such a strong effect at this scale.

Two key insights, relating to avian influenza research and perhaps other topics with similar characteristics, can be gained from these findings. The first builds on the fact that avian influenza is a socio-technical issue beset by the uncertainty and ambiguity of its problem framings, as first evidenced by the types of debates held in science policy and health policy. We found that influenza research is characterised by a wide diversity of perspectives on how social and technological interventions can mitigate the risk of a global pandemic. In terms of research agendas, we also describe how disparate options (epidemiology vs. virology or laboratory work vs. fieldwork) are advocated by different stakeholders. These divergences paint the picture of an area of low consensus on values and of high uncertainty, which in terms of science advice points to the need for a wide range of policy options. In particular, policy options should integrate a diverse set of perspectives so as to allow plural and conditional science advice (Pielke, 2007, Chapter 5; Leach & Scoones, 2013).

In this context, the difficulty is in capturing the different ways of reconciling societal *demands* (i.e., the outcomes expected from research by policymakers and other stakeholders) with science *supply* (i.e., the actual and potential outputs of research), and the challenges of linking the relevant areas of knowledge and actors (Sarewitz & Pielke, 2007, Wallace & Rafols, 2015). Since under conditions of uncertainty and lack of value agreement one cannot separate problem analysis from decision-making (Pielke, 2007), deliberations for research prioritization need to explore different perspectives about if and how the supply and demand are related, rather than allowing existing norms to "close down" the range of research options, analogous to what has been argued for the appraisal of technology (Stirling, 2008).

The second key insight is that private sector investment (e.g., towards the development of vaccines and antivirals) and "excellence"-oriented academic drivers (particularly those broadly towards basic biomedical research) tend to be focused on a relatively narrow set of research agendas. This narrow focus does not respond to the diverse concerns of some stakeholders we found in expert interviews. In particular, public —especially "academic"—research institutions appear to put relatively little attention to research aimed at certain types of outcomes, for example those more related to animal health, detection methods, or ecology. This observation is consistent with recent findings on how public sector researchers select topics and "negotiate" their research space (Luukkonen & Thomas, 2016). While the mandates or policy directions of large national and international mission-driven research organizations (especially those focused on human health) are undoubtedly dominant in setting global research agendas, their impact is limited to their sphere of influence. However these organisation may be able to better link their research focus with desired outcomes. Interestingly, the need to obtain research grants and the pressure to publish is also lesser in these organizations.

This study has direct policy implications in terms of processes for allocation of research resources for avian influenza. Preparing for a pandemic should favour a pluralistic approach (Forster, 2012), particularly given the uncertainties and controversies associated with the research itself (e.g. the "dual-use" problem). Allocation of research and calls for research proposals should explicitly take into account how social and technological pathways to reducing the risk of a pandemic are reflected in the various research fields, which should be viewed not only in terms of traditional disciplinary divisions, but also in terms of the other "dichotomies" we have revealed (e.g. laboratory vs. field work or global vs. local). In other words, research portfolio management should be informed by *contrasting* framings and ontologies. The management should not rely only on pre-existing research categories or "labels", but rather map new research options and diverse potential outcomes.

This study has also broader relevance for managing research to address complex societal challenges or for how science policy responds to "shocks" with a rapid influx of research resources, such as widespread concern over the Zika virus that emerged in 2015-2016. It suggests that for a given issue, a first step in priority setting is to acknowledge the existence of a broad range of possible relevant research outcomes and many possible research options for achieving them. Most importantly, in addition to resource allocation decisions, designs for governance of research should explicitly take into account the institutional pressures in place that shape research agendas and the uptake of knowledge. There is an opportunity to catalyze multi-stakeholder fora to engage in a meaningful debate on research resource allocation and incentive structures, ultimately leading to a more genuine evidence-based science policy.

6. Acknowledgements

We thank Jordi Molas-Gallart, Jochen Gläser, Grit Laudel, Andy Stirling and Richard Woolley for fruitful discussions, as well as reviewers in Research Policy and the SPRU Working Papers Series (SWPS). We acknowledge support from the FP7 EU Marie Curie Integration Grant to IR (MapRePort).

7. References

Abeysinghe, S., & White, K. (2011). The avian influenza pandemic: Discourses of risk, contagion and preparation in Australia. *Health, Risk & Society*, *13*(4), 311–326.

Agarwal, P., & Searls, D. B. (2009). Can literature analysis identify innovation drivers in drug discovery? *Nature Reviews. Drug Discovery*, *8*(11), 865–78.

Barrett, R., & Brown, P. J. (2008). Stigma in the time of influenza: social and institutional responses to pandemic emergencies. *The Journal of Infectious Diseases*, *197 Suppl* (Suppl 1), S34–S7.

Benner, M., & Sandström, U. (2000). Institutionalizing the triple helix: research funding and norms in the academic system. *Research Policy*, 29(2), 291-301.

Burgess, J., Stirling, A., Clark, J., Davies, G., Earmes, M., Staley, K., and Williamson, S. (2007). Deliberative mapping: a novel analytic-deliberative methodology to support contested science-policy decisions. *Public Understanding of Science*, 16(3), 299-322.

Butler, L. (2003). Explaining Australia's increased share of ISI publications—the effects of a funding formula based on publication counts. *Research Policy*, *32*(1), 143–155.

Chien, Y.-J. (2013). *Constructing Knowledge and Policies on Avian Influenza: How Do International Organizations Craft Global Models*. PhD Thesis, University of Minnesota.

Cassi, L., Lahatte, A., Rafols, I., Sautier, P., & De Turckheim, E. (2017). Improving fitness: Mapping research priorities against societal needs on obesity. *Journal of Informetrics*, *11*(4), 1095-1113.

Ciarli, T. and Rafols, I. (In press) The Relation between Research Priorities and Societal Demands: The Case of Rice. Research Policy. Available at SSRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3093285.

Costas, R., & Leeuwen, T. N. (2012). Approaching the "reward triangle": General analysis of the presence of funding acknowledgments and "peer interactive communication" in scientific publications. *Journal of the Association for Information Science and Technology*, *63*(8), 1647-1661.

Dawood, F. S., Iuliano, A. D., Reed, C., Meltzer, M. I., Shay, D. K., Cheng, P.-Y., … Widdowson, M.-A. (2012). Estimated global mortality associated with the first 12 months of 2009 pandemic influenza A H1N1 virus circulation: a modelling study. *The Lancet Infectious Diseases*, *12*(9), 687–695.

Rijcke, S. D., Wouters, P. F., Rushforth, A. D., Franssen, T. P., & Hammarfelt, B. (2016). Evaluation practices and effects of indicator use—a literature review. *Research Evaluation*, *25*(2), 161-169.

Edwards, B., Revill, J., & Bezuidenhout, L. (2014). From Cases to Capacity? A Critical Reflection on the Role of "Ethical Dilemmas" in the Development of Dual-Use Governance. *Science and Engineering Ethics*, *20*(2), 571–582.

Evans, J. A, Shim, J.-M., & Ioannidis, J. P. A. (2014). Attention to local health burden and the global disparity of health research. *PloS One*, *9*(4), e90147.

Ferguson, N. M., Cummings, D. A T., Fraser, C., Cajka, J. C., Cooley, P. C., & Burke, D. S. (2006). Strategies for mitigating an influenza pandemic. *Nature*, *442*(7101), 448–452.

Fidler, D. P. (2010). Negotiating equitable access to influenza vaccines: global health diplomacy and the controversies surrounding avian influenza H5N1 and pandemic influenza H1N1. *PLoS Medicine*, *7*(5), e1000247.

Foray, D., Mowery, D. C., & Nelson, R. R. (2012). Public R&D and social challenges: What lessons from mission R&D programs? *Research Policy*, *41*(10), 1697–1702. doi:10.1016/j.respol.2012.07.011

Forster, P. (2012). *To Pandemic or Not? Reconfiguring Global Responses to Influenza*. Brighton.

Friede, M., Palkonyay, L., Alfonso, C., Pervikov, Y., Torelli, G., Wood, D., & Kieny, M. P. (2011). WHO initiative to increase global and equitable access to influenza vaccine in the event of a pandemic: supporting developing country production capacity through technology transfer. *Vaccine*, *29 Suppl 1*, A2–7.

Frickel, S., & Moore, K. (Eds.). (2006). *The new political sociology of science: Institutions, networks, and power*. Univ of Wisconsin Press.

Frickel, S., Gibbon, S., Howard, J., Kempner, J., Ottinger, G. & Hess, D.J. (2009). Undone Science: Charting Social Movement and Civil Society Challenges to Research Agenda Setting. *Science, Technology and Human Values*, 35(4), 444-473.

Fung, T.K., Namkoong, K. & Brossard, D. (2011). Media, Social Proximity, and Risk: A Comparative Analysis of Newspaper Coverage of Avian Flu in Hong Kong and in the United States. *Journal of Health Communication*, 16(8), 889-907.

Gläser, J. & Laudel, G. (2016). Governing Science: How Science Policy Shapes Research Content. E*uropean Journal of Sociology* 57, 117-168.Global Health Watch. (2011). *Global Health Watch 3: An alterantive World Health Report*. London: Zed Books.

Godin, B. (2001). Neglected scientific activities: The (non) measurement of related scientific activities. Project on the History and Sociology of S&T Statistics, Paper No. 4.

Goldfarb, B. (2008). The effect of government contracting on academic research: Does the source of funding affect scientific output? *Research Policy*, *37*(1), 41–58.

Goodman, C.A. & Mills, A.J. (1999). The evidence base on the cost-effectiveness of malaria control measures in Africa. *Health Policy and Planning* 14(4), 301-312.

Gostin, L. (2006). Public health strategies for pandemic influenza: ethics and the law. JAMA, 295 (14): 1700-1704.

Gulbrandsen, M., & Smeby, J.-C. (2005). Industry funding and university professors' research performance. *Research Policy*, *34*(6), 932–950.

Head, M. G., Fitchett, J. R., Cooke, M. K., Wurie, F. B., Hayward, a. C., Lipman, M. C., & Atun, R. (2014). Investments in respiratory infectious disease research 1997-2010: a systematic analysis of UK funding. *BMJ Open*, *4*, e004600–e004600.

Heinze, T., Shapira, P., Rogers, J. D., & Senker, J. M. (2009). Organizational and institutional influences on creativity in scientific research. *Research Policy*, *38*(4), 610–623.

Hellstrom, T. & Jacob, M. (2012). Revisiting 'Weinberg's Choice': Classic Tensions in the Concept of Scientific Merit. *Minerva, 50*(3), 381-396.

Herfst, S., Schrauwen, E. J. a, Linster, M., Chutinimitkul, S., de Wit, E., Munster, V. J., … Fouchier, R. a M. (2012). Airborne transmission of influenza A/H5N1 virus between ferrets. *Science (New York, N.Y.)*, *336*(6088), 1534–41.

Hess, D. J. (2007). *Alternative pathways in science and industry: Activism, innovation, and the environment in an era of globalization*. Cambridge, MA: MIT Press.

Jasanoff, S. (Ed.). (2004). *States of Knowledge: the co-production of science and social order*. London: Routledge.

King, N. B. (2002). Security, Disease, Commerce: Ideologies of Postcolonial Global Health. *Social Studies of Science*, *32*(5-6), 763–789.

Laudel, G. (2005). Is external research funding a valid indicator for research performance? *Research Evaluation*, *14*(1), 27–34.

Laudel, G. (2006). The art of getting funded: How scientists adapt to their funding conditions. *Science and Public Policy* , *33* (7), 489–504.

Laudel, G., & Gläser, J. (2014). Beyond breakthrough research: Epistemic properties of research and their consequences for research funding. *Research Policy*, *43*(7), 1204–1216.

Leach, M. & Scoones, I. (2013). The social and political lives of zoonotic disease models: Narratives, science and policy. *Social Science and Medicine*, 88, 10-17.

Lindenbaum, S. (2001). Kuru, prions, and human affairs: Thinking about epidemics. *Annual Review of Anthropology*, *30*, 365–385.

Luukonen, T. & Thomas, D.A. (2016). The 'Negotiated Space' of University Researchers' Pursuit of a Research Agenda. *Minerva* 54(1), 99-127.

Miller, E., Andrews, N., Stellitano, L., Stowe, J., Winstone, A. M., Shneerson, J., & Verity, C. (2013). Risk of narcolepsy in children and young people receiving AS03 adjuvanted pandemic A/H1N1 2009 influenza vaccine: retrospective analysis. *BMJ (Clinical Research Ed.)*, *346*(February), f794.

Nicoll, A. & Coulombier, D. (2009). Europe's initial experience with pandemic (H1N1) 2009 - mitigation and delaying policies and practices. *Eurosurveillance* 14(29), 198279.

Nightingale, P., & Scott, A. (2007). Peer review and the relevance gap: Ten suggestions for policy-makers. *Science and Public Policy* , *34* (8), 543–553.

Payne, D. (2012). Tamiflu: the battle for secret drug data. *BMJ*, *345*, e7303–e7303.

Pielke, R. (2007). *The Honest Broker: Making Sense of Science in Policy and Politics.* Cambridge (U.K.): Cambridge University Press.

Quinn, T. (2008). *Flu: A Social History of Influenza*. London: New Holland Publishers.

Rafols, I., Porter, A. L., & Leydesdorff, L. (2010). Science overlay maps: A new tool for research policy and library management. *Journal of the American Society for information Science and Technology*, 61(9), 1871-1887.

Rafols, I., & Leydesdorff, L. (2009). Content‐based and algorithmic classifications of journals: Perspectives on the dynamics of scientific communication and indexer effects. *Journal of the Association for Information Science and Technology*, *60*(9), 1823-1835.

Rafols, I., and Yegros, A. (2018) Is research responding to health needs? *Social Observatory of La Caixa Foundation* (refereed online publication), March 2018. Accessed on 22 June 2018 at https://observatoriosociallacaixa.org/en/-/responde-la-investigacion-a-las-necesidades-de-salud

Reed, S. G., Bertholet, S., Coler, R. N., & Friede, M. (2009). New horizons in adjuvants for vaccine development. *Trends in Immunology*, *30*(1), 23–32.

Rosenfield, P. L. (1992). The potential of transdisciplinary research for sustaining and extending linkages between the health and social sciences. *Social Science & Medicine*, *35*(11), 1343–1357.

Rotolo, D., & Leydesdorff, L. (2015). Matching Medline/PubMed data with Web of Knowledge: A routine in R language. *Journal of the Association for Information Science and Technology.*

Salter, L., Leiss, W., & Levy, E. (1988) Mandated Science: Science and Scientists in the Making of Standards. Dordrecht: Kluwer Publishers.

Sarewitz, D., & Pielke, R. a. (2007). The neglected heart of science policy: reconciling supply of and demand for science. *Environmental Science & Policy*, *10*(1), 5–16.

Sarewitz, D. (2016) Saving Science. *The New Atlantis*, no. 49, 4–40.

Scoones, I. (Ed.). (2010). *Avian Influenza: Science, Policy and Politics*. London: Routledge.

Scoones, I. and Forster, P. (2010). Unpacking the international response to avian influenza: actors, networks and narratives. In: *Avian Influenza: Science Policy and Policitics*. London: Routledge.

Shibayama, S., & Baba, Y. (2015). Impact-Oriented Science Policies and Scientific Publication Practices: The Case of Life Sciences in Japan. *Research Policy*, *44*(4), 936–950.

Shoenfeld, Y., & Agmon-Levin, N. (2011). "ASIA" - autoimmune/inflammatory syndrome induced by adjuvants. *Journal of Autoimmunity*, *36*(1), 4–8.

Stirling, A. (2007a). A general framework for analysing diversity in science, technology and society. *Journal of the Royal Society Interface*, *4*(15), 707-719.

Stirling, A. (2007b). Risk, precaution and science: towards a more constructive policy debate. *EMBO Reports*, *8*(4), 309–315.

Stirling, A. (2008). "Opening Up" and "Closing Down": Power, Participation, and Pluralism in the Social Appraisal of Technology. *Science, Technology and Human Values*, 33(2), 262-294.

Suk, J. E., Bartels, C., Broberg, E., Struelens, M. J., & Ozin, A. J. (2014). Dual-use research debates and public health: better integration would do no harm. *Frontiers in Public Health*, *2*(September), 114.

Tallon, D., Chard, J., & Dieppe, P. (2000). Relation between agendas of the research community and the research consumer. *The Lancet*, *355*(9220), 2037–2040.

Van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523–538. doi:10.1007/s11192-009-0146-3

Van Eck, N. J., Waltman, L., van Raan, A. F. J., Klautz, R. J. M., & Peul, W. C. (2013). Citation analysis may severely underestimate the impact of clinical research as compared to basic research. *PloS One*, *8*(4), e62395.

Waaijer, C. J. F., van Bochove, C. a, & van Eck, N. J. (2011). On the map: Nature and Science editorials. *Scientometrics*, *86*(1), 99–112.

Wallace, M.L. & Rafols, I. (2015). Research Portfolio Analysis in Science Policy: Moving from Financial Returns to Societal Benefits. *Minerva 53*, 89-115.

Waltman, L., Eck, N. J. Van, & Noyons, E. C. M. (2010). A unified approach to mapping and clustering of bibliometric networks, *Journal of Infometrics 4(4)*, 629-635.

Weinberg, A. (1963). Criteria for scientific choice. *Minerva 1(2)*, 159–171

Yaqub, O., & Nightingale, P. (2012). Vaccine innovation, translational research and the management of knowledge accumulation. *Social Science and Medicine*, *75*(12), 2143–2150.

Young, N. S., Ioannidis, J. P. a, & Al-Ubaydli, O. (2008). Why current publication practices may distort science. *PLoS Medicine*, *5*(10), e201.

Supplementary material: Research methodologies

Qualitative data

1. Interview structure and analysis

We asked 16 participants to discuss to following elements in semi-structured interviews:

- Their involvement in avian influenza research and their relationship with the research and the policy spheres
- Their views of avian influenza as a problem (issues to address, evolving priorities over time, etc.)
- Their views of the research landscape (perception of overall trends, key stakeholders or research groups, different fields or avenues of research)
- The specific elements of the research landscape (possible contributions of the fields, main beneficiaries, connections to different objectives, etc.)
- The role of public sector research on avian influenza and the composition of "ideal" research portfolios (criteria for including different elements, hypothetical distribution of funding across research options, connections between research options)
- Deviation of the "ideal" portfolio from the current one (what should be more or less emphasized and why)
- Main drivers for the actual distribution of research resources, with a focus on how research is broadly governed, including funding, uptake of research

A summary of the respondents is shown in Table 1 (main text). It assigns levels of technical expertise and policy focus. Those with formal research training and work in the research space would be ranked as having high levels of technical expertise. Those (including researchers) having science policy or health policy influence, through their organizations and their positions therein, would be ranked as having high levels of policy focus. In some cases, the expertise or policy influence is somewhat peripheral to avian influenza (e.g., dealing with infectious diseases or health policy advocacy in general), but their perspectives meant that their perspectives were valuable for this study. Scheduled and unscheduled probing questions were used to delve deeper into each element elements and into other related themes that interviewees sought to explore.

2. Interview analysis

The analysis of interviews focused on three key elements:

1) **Coding views of participants regarding their interpretation of outcomes of research**, using framings of risk to differentiate between them. Views of risk were extracted by analyzing the language and opinions surround the discussions of possible pandemics and solutions to minimize the risk and severity of one occurring. A basic dichotomous scale was used to differentiate the views along three axes (see Figure 5), based on the research contents that the participants chose to discuss most often.

2) **Coding how participants viewed differently the (negative) impact of different types of institutional factors** on how research agendas are set and how research is conducted. Similarly, the factors themselves emerge from what was most often discussed, though in some cases was not acknowledged at all (blank cells in Figure 11), while in others it pertained only to a subset of research in the area. Here, a simple 3-point scale was used to differentiate low, medium and high impact or levels of influence. The rationale for the opinions could be from personal experience, from direct observations or from an indirect understanding of the field; no distinction was made between the three.
3) **Examples to illustrate the views reflected in each of the two points above.** Here, our focus was on connecting narratives with evidence gleaned from the quantitative analysis of publications, or with existing literature on research-related avian influenza control measures. One cannot generalize anecdotal evidence as representative of a larger set of views, but one can glean insight into framings of different views.

Participant	Expertise		Understanding of risk			Perception of sources of influence (type of research indicated where specified by participant)			
	Technical knowledge of individual	**Policy focus of organization**	**Likelihood of future pandemic**	**Risk assessment process**	**Basis for effective risk mitigation**	**Private sector***	**Public funding**	**Scholarly publishing**	**Institutional missions**
1	high	med		informal	technological	high - vaccines	high	med	high
2	high	med	uncertain	informal	social	high	low	high	
3	high	med	certain	formal		med	high - epidemiology	high - epidemiology	
4	high	low	certain	informal	technological	med - vaccines	med	med	med
5	high	low			social	and immunology		high	high
6	high	low		informal	technological	med		med	med
7	med	high	uncertain		social	high	med - public health	high	
8	med	high	certain	formal	technological	low		low	high
9	med	high	certain	formal	technological	low	high - vaccines		med
10	med	high		formal	social		high - vaccines	high	high
11	med	med	certain		technological	high - vaccines	med	high - molecular biology	high
12	med	med		formal		low			
13	low	med		formal	social	med	low		med
14	low	med			social	high	med		

Table 1. Table summarizing the key data groupings extracted from interview data.

Quantitative data

1. Data retrieval

Records were retrieved through Medline using the MeSH terms for common strains of influenza associated with Avian flu (H5N1, H7N7, H7N9, H7N10), combined with the MeSH term ("Influenza in Birds"). All articles referring to the H1N1 strain were also downloaded for comparison. The download was performed in February 2014, yielding 5,177 articles associated specifically with avian influenza, of which 3,935 could be associated with entries in Web of Science, using the common "unique identifier" field. This recall rate was similar for both avian influenza and H1N1 strains, and was much weaker for earlier years in the dataset.

2. Bibliometric "maps": basemaps, local maps and overlay maps

The maps themselves provide a means of visualizing a network by setting the distances between terms as being inversely correlated with the degree of similarity between terms. This, in turn, is defined by how often two terms co-occur within the abstract of the same article. VOSViewer uses 1) a natural language processing algorithm to identify terms rather than individual words and treat words in terms of their root or stem (thus eliminating plurals, for instance) and removes common words such as "the"; 2) counts to analyze how often terms co-occur and how "relevant" they are based on how "random" their pattern of occurrence is, which allows the user to remove terms that rarely occur and that are not specific to a given area to improve clarity on the maps.

In general, one needs to take care that setting the threshold of most "relevant" terms (which exclude the common terms such as "influenza") and the minimum number of occurrences of a given term, does not change the overall shape of the map. However, this remains an imperfect process, as some words with no semantic relevance (e.g., "February" or "subject") remain, while others can be removed manually for clarity without affecting the maps themselves. Overall, an effort is made to keep ad hoc manual interventions to a minimum for the sake of replicability. In other words, maps have to be tested for robustness for various settings so as to ascertain that the perspective provided is not an artefact of the choice of parameters.

In order to create the overlay maps based on a given basemap, we apply the following procedure.

1) A unique identifier is assigned to each record in the entire set, along with its abstract and any desired "tags" (WoS subject category, country, impact factor, etc.) associated with each article. These "tags" can be used to generate subsets that can be "overlayed" onto the main dataset basemap later on.
2) The full list of records and abstracts is then imported into VOSViewer to create a basemap, applying thresholds for the number and "relevance" based on robustness of these parameters to variation (see below) and visibility of terms. This is the basemap, which lays out common positions of terms for all future maps.
3) Two files can be exported from VOSViewer: the "map" file containing the positions and weights (number of occurrences of a term) and the "doc-term relations", which associate each term with the set of documents that contains it.

4) The same process is repeated for a subset of the list of records and their unique identifiers to create a "local" map, but with very small thresholds to preserve all terms, regardless of their number of occurrences or relevance.
5) The "local" map file is then exported. The "network" file can also be exported to view the linkages between terms if needed.
6) For each term in the basemap, a new weight is computed based on the number of occurrences of terms found in the "local" map, using the "doc-term relations" file as an index between the terms and the records.
7) Terms contained in the basemap but not the "local" map are assigned a minimum weight of 0.5 to "visualize" their absence on the overlay map (in light grey). Their labels are removed. This new map file can then be imported into VOSViewer as an overlay map, provided that VOSViewer does not normalize the sizes *a posteriori*, so that overlays can be visually compared against one another.
8) If desired, an updated network file preserving only the links between elements in the local map can also be imported to visualize the links between nodes.

Essentially, we are fixing the locations of the terms found in the basemap, while adjusting the weight assigned to each term based on its occurrence of relative occurrence within a subset. Various settings were used to represent these overlays in order to visualize changes with respect to the basemap. For example, in some cases (e.g., Figure 7), it is useful to examine changes in occurrence or density with respect to the basemap. This is often referred to as a 'density' or 'heat map'. In other cases (Figure 8), it is more useful to keep the original information and visually represent the density or terms occurring in each subset, without additional normalization. In each case, the mapping and overlay technique is more practical, and is no less "rigorous", than presenting raw data or traditional statistical analysis (e.g., of differences in occurrence of words) for the purposes of our argument.

3. Funding acknowledgments and addresses

The Web of Science captures and analyzes the "acknowledgments" section of many articles they index in order to extract information primarily related to funding. A main challenge is that the information may be in any number of formats and has been captured only since 2009. There are many other challenges associated with using this information, which have been well documented in the literature (Costas and Leeuwen, 2012). First, many articles do not explicitly acknowledge funders, and the practices vary widely by field or discipline. For instance, in biomedical research, there is greater pressure to be transparent due to the risk of conflicts and the obligation to disclose conflicts of interest in many journals. Thus when one funding organisation appears in a funding acknowledgement, I can either because of funding or because of conflicts of interes. In certain fields of the humanities and social sciences, on the other hand, this practice is very rare. Second, the names of institutions may be written or abbreviated in any number of ways, making it difficult to accurately determine which organization is being acknowledged by which paper. Third, the levels of funding are not indicated, so it is impossible for us to quantify the level of support, an important caveat for reading the maps of Figure 8.

In our case, approximately 60% of articles retrieved contained a funding acknowledgment (as detected by Web of Science). From the list of funding institutions acknowledged, the VantagePoint program was used to do a first automated pass at "cleaning" the list of main funding organizations. Particular attention was paid to private-sector funding and to cleaning the names of the top 5 most prevalent companies that were acknowledged, in order to generate Figure 8.

We also examined the institutional addresses (Figure 9) associated with each of the publications identified. In this case, coverage is close to 100%. This serves as a proxy for understanding *where* the research takes place. Nevertheless, there are two main caveats. First, within a collaborative (co-authored) paper, there are usually several different affiliations (many authors and many affiliations per author), thus it is difficult to establish the main institutional setting for the research. To minimize this, we have sought out papers from academic, clinical and industrial settings where *only* the corresponding type of affiliation exists.

Recent papers in the SPRU Working Paper Series:

November 2015

Twenty Challenges for Innovation Studies. Ben Martin.

Innovative Procurement Frameworks for Energy Performance Contracting in the UK Public Sector. Colin Nolden, Steve Sorrell, Friedemann Polzin.

Services in Developing Economies: A new chance for catching-up? Gisela Di Meglio, Jorge Gallego, Andrés Maroto, Maria Savona.

Barriers to Innovation: Can Firm Age Help Lower Them? Gabriele Pellegrino.

December 2015

Explaining Variation in Medical Innovation: The Case of Vaccines, and the HIV AIDS effort. Ohid Yaqub.

Social Network and Private Provision of Public Goods. Bulat Sanditov, Saurabh Arora.

Experiments in Climate Governance. Lessons from a Systematic Review of Case Studies in Transition Research. Paula Kivimaa, Mikael Hildén, Dave Huitema, Andrew Jordan, Jens Newig.

Opening the Black Box of Energy Security: A Study of Conceptions of Electricity Security in the UK. Emily Cox.

January 2016

A Triple Helix Model of Medical Innovation: Supply, Demand, and Technological Capabilities in terms of Medical Subject Headings. Alexander Petersen, Daniele Rotolo, Loet Leydesdorff.

Suggested citation:
Matthew L. Wallace, Ismael Ràfols (2016) [*revised 2018*]. Institutional Shaping of Research Priorities: A Case Study on Avian Influenza. SPRU Working Paper Series (SWPS), 2016-02: 1-39. ISSN 2057-6668. Available at www.sussex.ac.uk/spru/swps2016-02

SPRU – Science Policy Research Unit
University of Sussex
Falmer, Brighton, BN1 9SL,United Kingdom
SPRU Website: www.sussex.ac.uk/spru
SPRU Twitter: @SPRU
SWPS Website: www.sussex.ac.uk/spru/research/swps