The Science of Impact and the Impact of Agricultural Science

Peter Midmore[1]

Professor of Economics, Aberystwyth Business School, Aberystwyth University

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Royal Dublin Society, Dublin, Ireland

Abstract

Research impact and its measurement are of increasing importance. This is particularly significant for agricultural science, which is expected to produce solutions to future challenges that will arise from population growth, climate change and ecosystem degradation. Much econometric effort has been devoted to analysis of investment in agricultural research and its effects on farm productivity. This analysis, reviewed here, has produced a consensus suggesting that returns are high, although they are achieved only after long lags. However, policymakers perceive the occurrence of impacts as too few, and poorly targeted with respect to their needs. An attribution gap between the outcomes of agricultural research and how they reach farmers has motivated evaluation of the process of transmission and translation of agricultural research outputs into ultimate impacts. This gap can be narrowed by Participatory Impact Pathway Analysis, implemented mostly so far in low income countries. However, it is a costly and cognitively complex approach. Content analysis of the UK's 2014 REF Impact Case Studies uncovers the mind set of researchers and their managers regarding the description of impact and how it is supposed to occur. This reveals a nascent conservatism that focuses on research that can be shown to have impact, rather than research impact itself. From the overall discussion it can be concluded that the impact evaluation of agricultural science raises more profound issues than either efficiency or transparency. Confirmation bias threatens impact evaluation, principally by distracting from other important stories about how and why the ultimate effects occur, but also by transforming the nature of the process itself. Methodological pluralism, with greater integration and triangulation between different evaluation approaches, is a promising means of resolving these problems.

Keywords: Agricultural science; Research impact; Innovation systems; Institutional learning and change.

JEL classifications: H43; O31; Q16

1. Introduction

Research impact is defined by the Australian Research Council as "the demonstrable contribution that research makes to the economy, society, culture, national security, public policy or services, health, the environment, or quality of life, beyond contributions to academia".[2] The need to

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[2] http://www.arc.gov.au/research-impact-principles-and-framework.

demonstrate evidence of impact by academic and non-academic researchers is increasing, especially as the resources provided for public research have become relatively scarce. In response, methods to measure and monitor science's impact have developed. These compare what would have happened with or without the underpinning research, and are designed to establish how research leads to desired outcomes, and the extent to which any outside influences might have affected them.

Agricultural science faces particular challenges from internationally-shared problems, principally to meet food demands of a growing global population, to adapt to climate change, and to reduce ecosystem pressures. These are often described in the form of a trilemma (e.g. Steinbuks and Hertel, 2016), for which sustainable intensification (Pretty, 1997) is the remedy that only agricultural science and scientists can provide. Nevertheless, because various types of market failure affect the agricultural industry, it is unlikely that appropriate and sufficient research effort in agricultural science will be entirely market-driven. They include the public good nature of research, imperfect competition up and down the value chain linked to farm businesses, and social, spatial and environmental externalities. In the United States and elsewhere, these are compounded by a degree of government failure in that "…agricultural R&D has not been among the top priorities for the farm lobby, and continues to account for only a few (shrinking) percent of the total spending in the Farm Bill" (Gray *et al*., 2012: 7). The implication is that, relative to other parts of the economy, there will be under-investment in private agricultural research, and hence there should be public support to invest, not only non-commercial agricultural research areas, but also to correct for missing incentives to undertake applied, commercially relevant science. In the United States and elsewhere, these effects are compounded by a degree of government failure: "…agricultural R&D has not been among the top priorities for the farm lobby, and continues to account for only a few (shrinking) percent of the total spending in the Farm Bill" (Gray *et al*., 2012: 7).

For the United Kingdom, rapid growth in agricultural output occurred between the 1940s and the 1980s. Brassley (2000) explains that a large proportion of this growth, sometimes described as a second, 'quiet' agricultural revolution, arose from science-based innovations developed in the 1930s, although such advances were not adopted until market and policy conditions improved following the Second World War. Across Europe as a whole between 1950 and 1985, mechanisation, better-quality agrochemicals, intensive methods of livestock rearing, improved genetics, access to credit, and in Mediterranean regions, irrigation, contributed to very substantial increases in the volumes of agricultural output (Martín-Retortillo and Pinilla, 2015). The main contributions to this growth came, respectively, from increased capital deployment, and from total factor productivity growth. The authors argue that this growth was primarily stimulated by public research efforts, while public agricultural extension expedited uptake of the resulting new technologies.

Alongside and corresponding with this growth, however, a critique arose with regard to ensuing environmental, structural and aesthetic damage (e.g. Carson, 1963; Bowers and Cheshire, 1983; Shoard, 1987). Their concerns provided a convenient backdrop for the post-productivist shift in EU farm policy beyond 1985. With decoupling of policy supports and added effort to diminish the environmental damage associated with agricultural intensification, agricultural capital use declined (mainly in Western and Scandinavian parts of the continent) but total factor productivity continued to increase. This maintained (or offset the effect of diminishing factor use on) levels of agricultural output.

Consequently, it is more or less taken for granted that more agricultural science, suitably combined with extension efforts, would be desirable from the point of view of overall human welfare, solving major incipient problems through the efficient use of public financial resources. However, unlike other sectors of the economy, indicators used to determine the effectiveness of research spending (patents, e.g. Teitel, 1994; or development of new products or processes, OECD, 2010) are inappropriate, especially when correcting for market failure. Hence a substantial amount of intellectual effort has been devoted to measuring impact beyond effects on productivity. Interest in agricultural science impact, and the prevalence of studies on it, has mounted as pressure to demonstrate value for money has intensified. In part this indicates concern among policymakers that public science produces less than desired impacts and that basic science that pursued knowledge for its own sake should be curtailed "… in order to redirect researchers to work on "applied" projects that would bring more immediate discernible economic pay-offs" (Dasgupta and David, 1994: 588).

The focus here is on issues that arise in determining the impacts that may, or may not, originate from scientific research on agriculture. To begin, a short review and commentary on econometric evidence of the impacts of agricultural research draws out the central idea of science and innovation as the motor of agricultural growth and development. Other styles of impact evaluation come from a conceptual shift from 'knowledge transfer' to 'knowledge exchange', the counterpart to Gibbons *et al*.'s (1994) categorisation of Mode 1 and Mode 2 forms of knowledge generation. They suggest that impact generation potential could be improved by switching from the former hierarchical, autonomous and discipline-based science, to the latter which is based on more distributed, interactive, accountable and trans-disciplinary approaches. New, rich and extensive material on research impact augments these discussions. In 2014, for the first time, research impact outside of academia was assessed as part of the Research Excellence Framework conducted in the UK. Case studies of impact provided by universities were the main data provided for assessment, and these are available from an online database. Content analysis of the agricultural science cases provides much insight, not necessarily into impacts themselves, or their reach and significance, but into how university researchers and their managers regard and portray the impacts of their work. Conclusions address policy and practice implications of a tension between researcher professionalism and the successive regulatory layers being imposed upon it, and speculate on the impacts of impact evaluation itself.

2. Economic evaluation of agricultural science impacts

There is a large, and still expanding, literature on the rate of return on investment in agricultural science. Demonstrations of the impact of research investment on agricultural productivity have been extensively investigated by the many followers of Griliches (David, 2015). Economic theory, in particular, has focused on the effect of science-based innovation in raising productive efficiency. Increased productivity creates additional surpluses that allow rewards to production factors to increase, or final consumers to benefit from lower prices, or a combination of the two. Conceptually, the approach is based on rightward shifts of an agricultural supply function which arise as an impact from investment in research. Such shifts can either be within a particular sector of farming activity, or for aggregate agricultural output as a whole. Empirical analysis raises a number of challenges associated with the modelling of market behaviour through time. These include index number issues involved in the measurement of productivity, which in themselves are difficult enough to resolve (Ball, 2012; Capalbo and Vo, 2015). It is even more challenging, though, to discern the effects of spending on science, as the latter is cumulative, and often unpredictably susceptible to surprise. Spending (public and private) on agricultural research may, but does not always, lead to technical innovation. Then, as a result of the dispersed and fragmented structure of agricultural businesses, there are lags between the introduction of innovations and the diffusion and adoption processes. Further, from an analytic point of view, multicollinearity between lagged variables causes major difficulties in the estimation of delayed impacts. As well as accounting for this process, intertemporal comparisons require rendering into present values through discounting.

While the methods, purposes, scope and institutional contexts of such studies vary widely, and there is considerable discrepancy in the Internal Rates of Return (IRRs) that they (either directly, or implicitly) deduce, the striking conclusion is that investment returns in agricultural science are very high, indicating that the costs of public research investment would be considerably outweighed by collective benefits that ensue (Alston, *et al*.,, 1995). A systematic review by Alston *et al*. (2000b) produced an average IRR of 64.6%. Similar conclusions come from different studies by Evenson (2002), and Fuglie and Heisey (2007). For a British comparison, Thirtle *et al*. (2008), using a range of different lag structures, provided estimated IRRs of between 21% and 71%. On the basis of the model selection criteria the preferred value was 26% per annum. In a more recent, narrative, global review of overall state-supported agricultural investment, Mogues *et al*. (2012: 27) concluded that "dollar-for-dollar impact of public investments on the value of agricultural production is consistently highest, and substantially so, in agricultural research". Such returns are considerably above what might normally be acceptable for commercial ventures, and an order of magnitude greater than costs of public reflected in generally accepted levels of social discount rate.

The very high benefit-cost ratios of agricultural science impact are obviously of some concern. The meta-analysis conducted by Alston *et al*. (2000b) was designed to address causes of systematic and other bias that might inflate IRR estimates. The main conclusions were that spill-overs, both spatial and commercial, and the lag structures employed, had most impact on the scale of estimated IRRs. Refinement of the treatment of these would reduce any bias in the estimates. More recent work (Alston *et al*., 2010), which has focused exclusively in the USA, addresses these points. Careful assemblage of historic data on research expenditure in individual states enabled better attribution of spatial spill overs and much longer lags to be modelled. The functional form of the latter reflects the slow gestation and long-lasting influence of research impacts in a gradually depreciating knowledge stock. Within-state estimates averaged 18.9%, across-state estimates averaged 22.9%, and intramural research conducted by the USDA returned 18.7% per annum. These results are more credible in comparison with some of the more extravagant values reported earlier, but still large enough to show "handsome dividends", and very much in the public interest to invest more.

Against this backdrop, concern expressed about recent aggregate global shifts in public investment in agricultural science is unsurprising. While governments in the United States and Europe as a whole have contracted their levels of support, middle income countries such as India, China and Brazil have increased both their relative share and absolute levels of expenditure. While private sector investment is also increasing globally, nevertheless "the continued comparatively low levels of investment in many poorer countries … are concerning" (Pardey *et al*., 2016: 303; see also Beintema *et al*., 2012). The distortion of private incentives by various market failures and social traps are a long way from being overcome, and policymakers have not taken up the message, at least at its face value. This is in essence what might be termed the 'Alston paradox'[3]: that even though there is good evidence both of the effectiveness with which it creates impact, and of the worrying slump in agricultural productivity at a time when the global population is growing and productive resources are vulnerable to climate change, government spending on agricultural science research is in long-term decline.

The majority of econometric evidence is based solely on impacts within commodity markets, due to difficulties in conceptualising and measuring the other variables that might embody impact. In Europe, where environmental objectives have grown in prominence in agricultural policy objectives and measures, the impacts of research will not necessarily be reflected in productivity gains (for example, Barnes, 2002; Nanere, 2007; for a more qualified view see Byerlee and Murgai, 2001). Social science and policy research should also in principle be generating impacts. However, the noisiness of other influences may significantly overshadow any consequences from research that may flow for improved social welfare. Zilberman and Heiman's (1999:20) investigation of the benefits of agricultural economics research, in terms of enhanced information, technological change, and improved policy efficiency, concluded that "(o)ne of the most difficult obstacles in preparing an assessment of the benefits of economic research is a lack of evidence."

Yet it seems unlikely that taking either of these issues into account would resolve the Alston paradox. Another potential, if speculative, response comes from consideration of the lengthy interval between increments to the knowledge stock and their eventual impact. The broad consensus from studies suggests that these will range over several decades. On the basis of lag lengths preferred by Alston *et al*. (2009), most current impacts on productivity should stem from research undertaken around 1993, and activity from as far back as 1967 might also still be having some effects. The stock-flow knowledge model which underlies most analyses is an abstract conception. Strong resonances of capital, investment and depreciation provide intuitive appeal for agricultural science's activities to result in a store of 'knowledge treasure'.[4] Moreover, it is also very useful for making the problem of lagged impacts of research expenditure analytically tractable.

However, the process of transmission, via diffusion and adoption, has clearly experienced dramatic upheavals since the early 1990s. For example, in the Netherlands, Poppe (2008) has identified a range of public actions designed to improve the fungibility of science-generated knowledge stocks that are potentially useful for agriculture. These included privatisation of extension services, merger and financial restructuring, abolition of commodity marketing boards, introduction of public-private collaborations in innovation, fostering new business models for agriculture, sponsoring agri-food industrial districts, and improving research and education links. Alongside these sector-specific changes, it is important to remember that the internet has wrought transformative effects on science-based knowledge availability since the mid-1990s. Hence the ability of the overall system in which the effects are felt has the capacity to change and, importantly, to be changed by, the original science, which could undermine the implicit econometric assumption of an essentially stable impact transmission system over long periods of time.

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[3] Often noted by Julian Alston and collaborators, and most extensively expressed in Alston *et al*. (2000a: 5-6).
[4] However, as Immanuel Kant observed in The Critique of Pure Reason (2009: 645), "we may as well hope to increase our stock of knowledge by the aid of mere ideas, as the merchant to augment his wealth by the addition of noughts to his cash account." Rather, it depends on the uses to which these ideas are put.

3. Pathways to agricultural science impacts

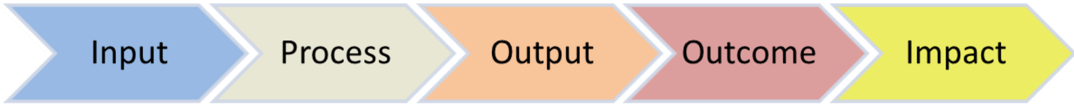
Alternative narratives suggest that agricultural knowledge and innovation systems are far from stable. Agricultural science is a socially structured and organised activity consisting of both scientists and the institutional framework in which they operate. This actor-network system is extended through links with other science-based institutions, and further influenced by the policy and commercial world. Through these relationships, farms and allied businesses pick and mix available technologies and adopt and adapt in order to further innovate in a way appropriate to the extensive individual heterogeneity in which they operate. Kloppenburg (1991) draws on feminist and sociological interpretations of science to restore attention to the role of farmers' use of informal, site-specific knowledge of local biological and climatic conditions to adapt technical innovations for adoption. Similarly, Röling (1996) deploys a constructivist epistemology to suggest the need for an interactive agricultural science, making better use of this latent, informal knowledge of farmers to produce more precisely focused science-based agricultural innovations. Carolan (2006) explores relations of trust and knowledge in agricultural social networks to distinguish between competing agricultural narratives (conventional and 'alternative') and how they are received. Vanloqueren and Baret (2009) describe how the existing powerful technological regime is maintained through path dependence. They consequence they describe is that this regime locks out alternative agricultural sciences, particularly those with the potential to resolve problems arising from climate change, and that address the need for more sustainable farming systems.

Policymakers' concerns that research on agriculture is not producing enough impact reinforce this alternative perspective. For example, the UK Government (BIS, 2013: 8) recognises that while "We have institutes and university departments at the forefront of areas of research vital to agriculture", nevertheless "the infrastructure to support industry in applying science and technology to help modern farming and food production has declined over the past 30 years". The perceived need to better translate that excellence into improved farming performance has resulted in a major recent shift of public agricultural research expenditure. Since 2013 the majority of public effort is combined with commercial partners into the Agri-Tech programme, which is designed to overcome barriers in the process of translating science into impact. Similarly, the EU Standing Committee on Agricultural Research established a Collaborative Working Group in 2009 to coordinate and develop Agricultural Knowledge and Innovation Systems. It recognises a discrepancy between science-driven research and innovation-driven research, noting that, with regard to the relationship between them, "valorisation of research results, the responsiveness of research to its own content and access to results are all issues that need to be addressed" (SCAR, 2012: p.32). Pollock (2012: 3) goes further and suggests that: "(f)ailure to transfer knowledge effectively negates much of the value in creating it", such that there is a "fractured pipeline" between science-generated knowledge and farming practice.

3.1. The Logical Framework

Chris Pollock's metaphor is consistent with the logical framework (or logframe) model of research impact (Coleman, 1987), which portrays the process as a singular, unidirectional flow from knowledge makers to knowledge users. This causal, or 'results', chain attributing impacts to their origin is illustrated in Figure 1.

Figure 1: The Logframe as Expression of a Results Chain



Source: adapted from DfID, 2009

Inputs of human and other resources are mobilised in the research process itself. From this activity, the knowledge created is embodied in the form of products, capital goods and services, and constitutes research outputs. These outputs are linked to the short-term and medium-term effects, or outcomes, that they produce. Outcomes spill over into direct and indirect longer term effects, whether favourable and detrimental, which are recognised as the ultimate impacts of the initial research funding.

The logframe is still commonly used by public science funders as a tool to assess, ex-ante, the potential for beneficial socio-economic and other outcomes that need to be considered prior to project initiation.[5] This involves significant challenges, in categorising and recognising each stage in the transfer mechanism, and then to reduce their respective operation to accurate and measurable instruments and indicators (Godin and Doré, 2004). However, more trenchant criticisms are made by Springer-Heinze *et al*., (2003), in particular regarding the complexity of interaction (including feedback loops) between researchers, intermediaries and the adopters of innovations, and of the failure to recognise alternative influences, hence implicitly attributing all impacts to the original intervention. Firstly, there is an attribution gap between direct benefits of project outputs and their influence on aggregate effects at impact level. In effect, between short-term outcomes and long-term impacts, other unrelated influences may intervene to either enhance or weaken the effects of research activity. Correspondingly, alongside the impacts envisioned by the logframe, unanticipated effects stemming from policy, social, or other influences may also occur. Second, there are reservations about the determinism of the unidirectional flow. Both research and the resulting innovations modify social contexts, implying that scientists should (and often do) take heed of the context for which their innovations are developed, and modify their own activities and objectives as a consequence.

Concerns about the usefulness of the logframe approach for identifying the effects of agricultural research found most fertile ground in analysis of impacts of donor-funded research activity in low income countries. In such contexts, insufficient lengths and quality of time-series data limit the scope of econometric modelling, and result in a search for alternatives such as pooling data from several countries (Alene and Coulibaly, 2009; Alene, 2010). This, though, does not address the attribution problem. The Consultative Group on Agricultural Research (CGIAR), responsible for coordinating international research on agriculture, food and ecosystems, established a Standing Panel on Impact Assessment in 1996, and has since conducted many studies to ensure value for money to supporting donors. Formerly, many economists employed in CGIAR-affiliated research Centers have undertaken *ex-ante* cost-benefit analyses to aid choice between and prioritisation of

[5] For example, the UK's Research Councils guidance requires impact summaries in this form to be included in proposal submissions (as specified by RCUK, 2011).

project proposals. Since 1997, however, the CGIAR Science Council has commissioned independent impact assessment and evaluation procedures. What is now its Standing Panel on Impact Assessment (SPIA) is tasked with providing "… timely, objective, comprehensive, credible and digestible information on a whole spectrum of realized impacts from past CGIAR research investments and resultant outputs in terms of the CGIAR goals of enhanced food and nutrition security, poverty reduction and enhanced natural resources".[6]

3.2. *Impact Pathways Analysis*

Impact Pathways Analysis (IPA: Douthwaite *et al*., 2003) is an evaluation approach now adopted widely within the CGIAR system of international agricultural research institutions. It envisions research pathways as embedded within wider economic, social and political frameworks, and recognises that uncertainties and unexpected combinations of circumstances might either hinder or facilitate the ultimate generation of impacts. Based on critical realism, it nevertheless provides a framework capable of complementing, rather than replacing, the positivist approach that dominates economic impact assessment. Drawing on both Farming Systems Research (Norman, 1978) and Program Theory Evaluation (Rossi *et al*., 2003), it has produced a framework that uses terminology familiar from logframe procedures. However, it recognises that relations between processes, outputs, outcomes and impacts are not necessarily sequential, or unique. It also provides for multiple pathways and feedback loops containing multilateral flows of knowledge, ideas and innovation. The theorised causal framework by which the inputs used ultimately produce impacts is made explicit through pathways that describe mechanisms of effect.

In its original formulation, IPA was developed through a two-stage procedure. The first step, implemented prior to project or programme implementation, established researchers' intended impacts. This step involved a process of self-evaluation. Through experiential learning, often with the aid of a problem tree diagram, milestones were mapped out to show the causal pathways to wider impacts. The second step, carried out some time after completion, provided a comprehensive evaluation framework for identifying and validating impacts, including those that were unanticipated at the outset. This summative step required assessment of the plausibility and persuasiveness of the links from outputs to impacts.

3.3. *Participatory Impact Pathways Analysis*

IPA was later adapted, in line with the concept of Mode 2 Science discussed above, to include stakeholder participation (Douthwaite *et al*., 2007; Alvarez *et al*., 2010). Participatory Impact Pathways Analysis (PIPA) takes account of actor and stakeholder views to ensure a relevant scientific focus on existing problems. It is designed to develop a more accurate and mutual understanding of the mechanisms (or 'theory of change') by which outputs produce outcomes, and subsequently impacts, and to then use this understanding to evaluate research effectiveness both during and after its implementation. The central feature of this adaptation is a workshop which includes researchers, actors who directly use research outputs and, even though they do not have direct involvement in the research itself, stakeholders who are able to influence the enabling environment. In the same way as IPA, workshops collectively identify and map impact pathways. However, an added dimension is development of network maps that describe collaborations and influences between actors and stakeholders, both existing and future, with the latter acting as a vision for improved

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[6] http://impact.cgiar.org/how-we-work/ia-at-cgiar (accessed 21st March 2017).

linkages, which can in turn enhance impact. Both elements are then distilled into a tabular representation of stakeholders and their required actions, to enable envisioned outcomes to be materialised. After the project, this table is used as the framework for checking and validating of impacts and the pathways through which they occur.

Despite its attractiveness, the scope for wide application of PIPA as an evaluation tool in low income countries is limited. It is very costly, since facilitators for the workshops and follow-up evaluations need specialised training, and its complexity may deter non-scientific actors from fully participating. While there are fewer constraints of this type in so-called advanced economies, evidence from literature suggests that take-up is slow, so far. Apart from Quiédeville *et al*. (2017) it has not been used to analyse the impact of agricultural science in Europe. Applications to other impact evaluation topics include educational innovation (Middlemas and Shaw, 2009) and rural broadband provision (Pant and Odame, 2016).

4. Agricultural science research impact in the recent UK REF

There has been an approximately quinquennial assessment of the quality of university research in the UK since 1992, conducted jointly by its four Higher Education Funding Councils (HEFCs) in the form of the Research Assessment Exercise, or RAE. Ratings have been applied to Units of Assessment (UoAs) that approximately correspond to the disciplinary basis of university departments. Until the most recent exercise, these ratings were mainly derived from expert ratings of published academic outputs, and complemented by measures of grant capture and indications of esteem. Renamed the Research Excellence Framework (REF) in 2014, a novel element, based on the impact of research beyond academia, was introduced. It was established “to assess the extent to which a submitted unit has built upon its strong record of excellent research to make a positive impact on the economy and society” (HEFCE, 2009: 7). This was the first ever attempt on a national scale to provide a comprehensive assessment of academic research impact.

The detailed rules for the REF (HEFCE 2012) required each UoA to submit two or more (depending on size) narrative Impact Case Studies (for brevity, subsequently referred to as cases). These were submitted in a prescribed format of limited length, including summaries of the impact, descriptions of underpinning research, details of the impacts, and sources for corroboration. Together with the minor element describing the UoAs’ strategy for achieving impact, these provided 20% of the overall rating of research quality. The remaining 80% was based on publication outputs and the other evidence reviewed in the RAE before 2014. It continued to use four main classes, profiling the proportion of work within each, ranging from world-leading to nationally relevant, with potential to give no grade (unclassified) to research that did not achieve the nationally relevant level. Criteria for assessment of impact were ‘reach’ and ‘significance’.

All of the case study evidence is available in a searchable on-line database.[7] This qualitative dataset can be used to extend discussion of agricultural science impact. The database only describes impacts of research performed in higher education, which in 2015, for example, represented only 25.3% of total R&D expenditure in the UK (Office of National Statistics, 2017). Moreover, it is not representative of University-based research, since institutions were encouraged to showcase only work that produced the best impacts; and activity by non-academic public or commercial

[7] Available at: http://impact.ref.ac.uk/CaseStudies/search1.aspx.

researchers is only reflected in the cases that involved their collaboration. Nonetheless, it is an extremely useful source of insight into how academic researchers, or their managers, view impact. The manner in which they describe their cases portrays what they think impact is, and how it is achieved. This gives an opportunity to assess how far different aspects of impact evaluation described in the two previous sections have become part of the custom and practice of agricultural science.

This section uses content analysis to explore the text of 'Descriptions of impact' sections in relevant agricultural science cases which appear to identify prominent narratives or rhetorical forms. Content analysis can be summarised as systematic quantitative description of the meaning of communication (see, for example, Krippendorff, 2013 or Neuendorf, 2016). While the method is generally used for exploration, description or inference, only the first two purposes are feasible in this instance. The way in which details of impacts are expressed and the form in which they are described can be elicited very readily from the online database. It would also be interesting to know how such characteristics influenced the expert panels and sub-panels that awarded the grades, and to develop a probabilistic predictive model based upon them. However, the policy of the HEFCs in assigning quality levels grades prevents this. Even though panels used a finer grading system of half-grades (Manville *et al*., 2015), quality levels were averaged across UoAs, and further blurred by awarding a small proportion to a description of the UoA's approach to enabling impact from its research.

The analysis identifies the relative frequencies of particular forms of impact and contentions about how they have been achieved. These aspects are illustrated with brief excerpts from the narratives themselves, chosen (subjectively) to typify the issue as a whole. Quotations are referenced by the REF Impact Case Study five-digit code used as identifiers in the HEFCE database.

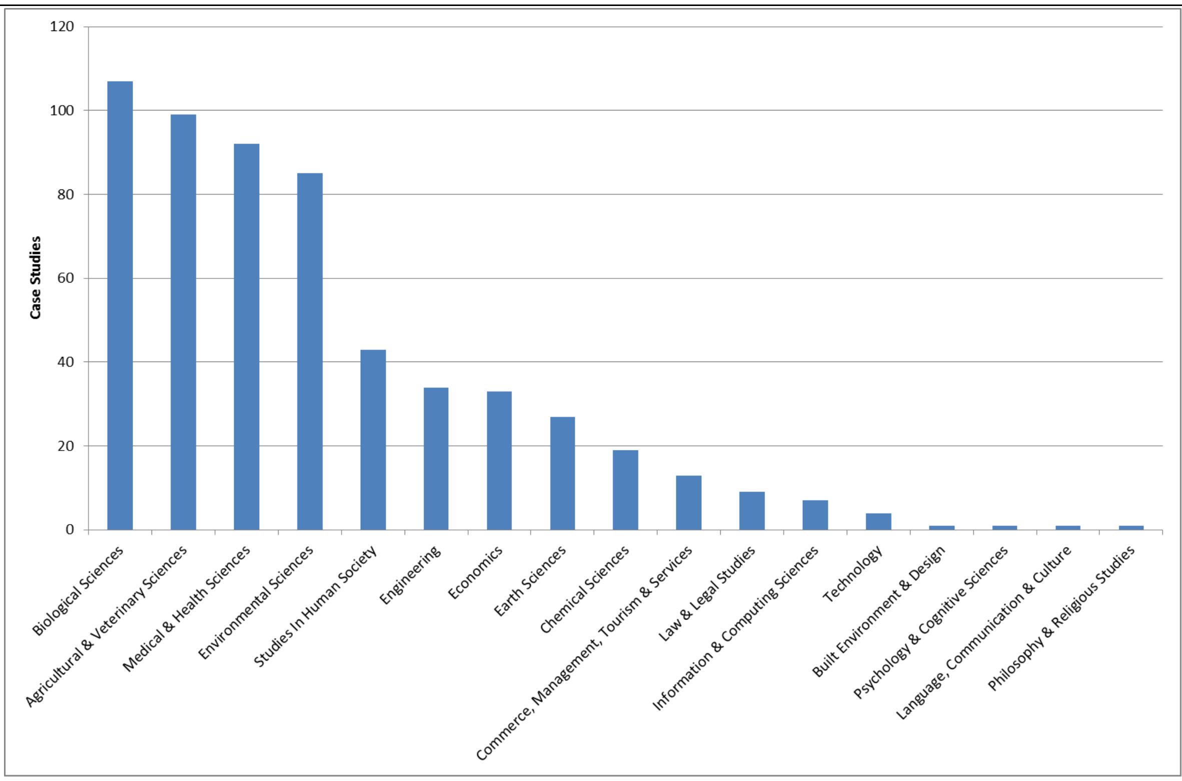
Deciding whether a case should be included in the analysis is, to an extent, arbitrary, especially as interdisciplinary cross-fertilisation between agricultural science and other disciplines has become an increasingly frequent occurrence. 125 published[8] cases were submitted to UoA6, which covers Agriculture, Veterinary and Food Science. Of these, however, a significant portion of 19 cases relate to companion animals, mostly cats, dogs and horses. Some knowledge spill overs may arise for other agricultural science activities, but consideration of these cases suggests that such links are weak and they have been excluded. A further 132 published cases list either Agricultural and Veterinary Sciences, or Food Sciences, as one of the three potential subject areas that underpin the research claiming impact.[9] 58 additional cases remained after removing duplicates and other cases that did not claim agricultural science impacts. Finally, it was clear that many other cases involving 'agriculture' and 'farming' could be found across a wide range of other subject areas, and a search on the stems of those two terms produced 664 cases. Of these, a considerable number were either irrelevant or duplicated cases from the two preceding searches, leaving 143 new cases for analysis. As an approximation, and given ambiguity concerning what is and is not an agricultural science-based impact, the 307 cases considered for analysis come close to an appropriate set.

[8] Some case studies notified by institutions as 'not for publication' were not included in the database.
[9] Only 47 of these were submitted to the Agriculture, Veterinary and Food Science UoA6, and thus 78 were based on other research subject areas.

This set includes 106 cases submitted to the Agriculture, Veterinary and Food Science sub-panel. In addition to these, it also includes 47 submitted to the Biological Sciences sub-panel, 34 to Geography, Environmental Studies and Archaeology, 28 to Earth Systems and Environmental Sciences, 17 to Business and Management Studies and 10 to Architecture, Built Environment and Planning. The remaining 65 included cases were scattered across 20 other panels.

To aid searching, cases in the online database have been pre-coded by the HEFCs using two indicative dimensions. The first of these is a single summary impact type based on a text analysis of the 'Summary of the impact' section of the case study template. The most prevalent impact types in the agricultural science set were environmental (49%) and technological (22%) with political (10%) and economic (9%) following up. The second distinguishes one to three research subject areas, also identified from a text analysis of the 'Underpinning research' section of the template. In terms of underpinning scientific subjects, the most important were Biological Sciences and Agricultural and Veterinary Sciences, followed by Medical and Health Sciences, and Environmental Sciences. Figure 2 shows the number of cases by research subject.

Figure 2: Agricultural Science REF Impact Case Studies by Research Subject



Source: HEFCE (http://impact.ref.ac.uk)

The first theme appearing in the set as a major pathway to impact relates to productivity enhancements, usually in the form of cost reductions. 86 cases describe reductions in costs or efficiency savings, for example "Improvements in efficiency … have resulted in lowering [*artificial insemination*] costs and expansion in its use" [15615], or "wider environmental benefits that arise from increased efficiency of resource use within mixed grazing systems are associated with enhanced productivity for upland farmers" [42083]. Monetary values are not always used to quantify economic impacts of research in terms of increases in profits or gross value added, or cost savings, or enhancements to farm income. In fact, while 160, or just over half of the cases, mention cash in any form, 55 of them only use monetary values to describe the overall context of their impacts, such as sizes or aggregate scales of costs (for example, "Obesity alone costs the NHS more than £5 billion every year"[21769], or "Hiprotal 60 sold at £6 per kilo which equates to approximate sales of £6M over the five year production period" [25832]). Another 25 report the value of grants undertaken to produce the impact, which more properly count as inputs to the results chain. Of the 86 which report a monetary consequence arising from the research, 37 can be categorised as producing outcomes, rather than impacts. For example "Cadbury now pays over £3 million per annum in social premiums to Kuapa Kokoo – a Fairtrade certified Cooperative" [28123], or "Extensive take-up by UK NHS Trusts and Local Authorities (investments of £1.9m, £1m respectively) demonstrates a policy shift" [23095]. This reflects a prevalent confusion between outcomes and impacts among researchers completing impact templates.

Monetary impacts are validly identified in 53 cases (4 cases illustrated both outcomes and impacts). Of the cases with summary impacts categorised by the HEFCs as economic, 21 of the 27 did not report impacts in monetary terms. A similar proportion (48 of 67) of those categorised as summary technological impacts did not report monetary impacts. The smallest annual aggregate value reported was £100,000, and the largest was $US4.5 billion. The range of values were roughly equally divided by into three, with about one third under £10 million, about one third between 10 and 100 million, and the remainder from £100 million up to billions of pounds. However, 18 of these values were described as estimates, some with attributions to independent sources, such as use of Treasury 'Green Book' methods, or established techniques ("a survey conducted in 2010 … estimated the benefit of [*Agri-Environment Schemes*] in England to be between £0.8 billion and £1.5 billion per year based on citizens' willingness to pay" [37263]). Others instead merely relied on assertion ("additional pre-tax profits [...] were expected to total £500K by the end of 2008" [11799]).

Just under half (140) of all cases reported impacts relating to commercial enterprises (other than farms), either directly on their performance or transmitted through them to final beneficiaries. A proportion of these (38) were via collaborative research with major multinational companies, including major agro-industrial firms such as Syngenta (12 cases), Monsanto (5 cases), and GlaxoSmithKline (3 cases), or food conglomerates such as Nestlé (5 cases) and Unilever (4 cases). One case argued that "on-going collaboration throughput the reporting period with Syngenta … was instrumental in developing a strategy focusing on output rather than input characteristics, for example, nutritional of food crops" [30237]. Links of various kinds with multiple retailers were evident in a further 29 cases, including Sainsburys (13 cases), Tesco (10 cases), Waitrose (8 cases) and Marks and Spencer (7 cases). For example the "E+™ Ethylene Remover … was launched commercially in 2009 and is now in use in packaging for most mainstream supermarkets in the UK (Tesco, Waitrose, M&S) and USA, where it has been shown to reduce wastage of a range of fruits and vegetables" [6434]. 12 cases described impacts on or through privatised Water utility companies, either in terms of lower costs or improved water quality, and these were prominent in cases coded as having summary impacts on the environment. At the other end of the business scale, 11 cases demonstrated commercialisation of research through spin-out companies. One example states that "[i]mpact is evidenced by the formation of the spin out company, Si Active, in 2009, which holds the patent to the bioavailable silica" [12702]. 27 cases have either applied for or obtained patent protection for their innovations (17 in cases with technological impact types). 11 have developed products with trademarks.

There were 187 cases which claimed influence over policy. Often the effects were complex and related to a number of themes. The largest number (86 cases) were concerned with environmental policy, with many of these related to flood management or water quality. One case claimed that its research provided the "primary evidence base for the subsequent policy document Making Space for Water; in turn it directly informed a multi-million pound uplift in the flood risk management budget announced by Defra in 2006" [1449]. In the next largest group were 55 cases relating to influence on agricultural policy, which had a considerable degree of overlap (17 cases) with those involving environmental policy. One overlap case involved the development of policies to mitigate greenhouse gas emissions from agriculture which "informed policy design by showing which measures can be implemented at a cost that is less than the government's benchmark cost for reducing carbon emissions" [23906]. Other prominent policies impacted by academic research included food (23 cases) fisheries (including fish farming and freshwater fisheries; 20 cases) and agricultural development (16 cases). Many of these impacts (in 167 cases) were achieved through advisory roles of various kinds, either by carrying out research for advisory bodies (57 cases) or by appointment to official or semi-official government positions (35 cases).

Another strand of impact relates to the food-energy-environment trilemma. Here the numbers of related cases are fewer. One case directly addresses the trilemma, "indicating that allowing land to specialise appropriately in producing food or ecosystem services can produce more of both than a 'one size fits all' approach of managing everywhere to produce both simultaneously" [6320]. Another recognises the context of "potentially conflicting agendas on biodiversity conservation, livelihoods and economic growth" [27040]. A third notes that "commercial benefits have already stimulated further international investment in projects that aim to improve our knowledge and consequently our ability to exploit the genetic diversity of wheat to improve yields in the face of a growing global population and environmental change" [40213].

Population growth and the increase in food demand are addressed by 8 cases, and a further 8 identify alleviation of agrarian-related poverty. In Palm Oil production, for instance "prevention of … [*the fungal diseases Fusarium and Ganoderma*] … and development of resistance to them also has significant quality of life benefits for the sustainable existence of smallholders and alleviating rural poverty" [43206]. Another claims that its electrostatic technology for environmentally friendly pest control achieved a grant to "use the same technology to reduce poverty of subsistence farmers in sub-Saharan Africa" [42990].

In various forms, climate change mitigation is addressed by 31 cases. Specifically, 7 focused on non-fossil fuel production, covering biogas and waste to energy processes, 3 addressed renewable power generation, including a community action project which implemented renewable energy solutions [21478], another where research combined with community activism established renewable wind energy on a Hebridean Island [38047], and an online windfarm carbon calculator [43296]. More efficient energy use was an outcome of 14 cases, such as the case describing an innovation which produced annual decreases of "between 8750 and 12500 kg of CO_2 per ha of greenhouse" [28293]. The largest category of 11 cases contributed to improved policy towards renewables. One noted that "Hansard cites links to our work in three White Papers between 2001 and 2005 and three policy briefings from the Parliamentary Office for Science and Technology […] findings have been presented through personal briefings to successive Secretaries of State for the Environment" [1449]. Often impacts were complex and indirect. For example a case claimed to work by "catalysing policy changes and measures to reduce carbon footprints and improve food production efficiency" [25249], and another case provided evidence of "the joint positive relationship between economic and environmental efficiency: lean is green" [35156]. Decreased soil erosion is an impact addressed in 7 cases, two relating to the UK and two to Sub-Saharan Africa, one each to Australia and China, and one claiming global reach: "improved soil management planning through enhanced spatial information has informed policy development related to soils at national, European and international levels, allowing nations to adopt new approaches for the soil mapping of their land mass, and more effective management of strategically important land assets" [6435].

Indications of Gibbons *et al*.,'s (1994) Mode 2 type of interactive approach to agricultural science are scant. 37 cases included discussion of extension or farm advisory services as the main conduit for transmission of research to achieve impacts in farmers, land managers or other subsequent beneficiaries. Searches for the term 'pathways to impact' produced 10 relevant cases, and 7 relevant cases for the term 'stakeholder engagement'. While expressed in the language of knowledge exchange, there was little difference in either group from the general way in which impacts were described in the overall set. Of the combination of 17 cases relevant to interactive ways of working, one was based on predicted impact only, rather than actual. Another [522] revolved around the publication of a legal report that paved the way for statutory reforms, with the author invited to serve on an advisory committee. One more "shaped diverse rural policy debates" [3469] through broad media coverage and direct dissemination of results to politicians and policymakers, also with the lead researcher appointed as special advisor to a Welsh Assembly Committee. Three [42799, 23908, 21478] noted the uptake of tools for, respectively, managing land for carbon, reporting on ecosystem health and managing improvements in soil quality as means of achieving impacts. Others [21701, 41279] used practitioner journals and conferences, workshops and meetings with actors and other stakeholders to engage outside the research community. Only three cases indicated any kind of feedback loop: a case describing the enhancement of cattle-based controls for bTB was "based around a 'pathways to impact' approach, has enabled the group's subsequent scientific outputs to be tailored towards the needs of policy development from the start" [17030]. The case based on the RELU programme established national stakeholder forums to act as "sounding boards on programme and project development and dissemination strategies" [21453]. A further example from research underlying a case on wildfire policy and practice was "particularly appealing to Fire Services who have given extensive guidance to follow-on work by the team" [28103].

A pervading impression from a reading of all of these cases is of caution, which is not surprising because of its newness and the fact that mistakes could be costly. The process of shortlisting and finessing case studies was observed in one Russell Group university as "an institutional strategy for upgrading impact case studies based on a presumption that rhetorical artifice and a combination of exegetical eloquence, economy and precision would invoke the largesse of REF panellists" (Watermeyer and Hedgecoe 2016: 661).

The public resources that follow the grading of cases are substantial: Reed and Kerridge (2017) estimate that a case classed as world-leading attracted £44,048 on average in 2016/17, whereas one classed as internationally excellent was paid only £11,813, but for cases classified as grade two or below, nothing is paid. While it is only a partial overlap with the set of cases analysed here, the total amount disbursed for impact in the same financial year in England for the universities that submitted

UoAs for the Agriculture, Veterinary and Food Science Panel was £3.8 million. The largest amount was £662,942, the smallest £51,277.

However, perhaps more importantly, cases provide for enhanced reputation and defence against an assumption of the impractical aloofness of academic research from practical matters or urgent problems. The above analysis is far from unique. Already the fruitfulness of searchable REF impact case studies database has been noticed and exploited by a number of researchers in other disciplines (Biri *et al*.,, 2014, assessed cases in built environment, engineering, and maths and physical sciences; Greenhalgh and Fahy, 2015, explore cases in community-based health sciences; Morrow, 2015, examined cases for leadership, governance and management in Higher Education; and Robbins *et al*.,, 2017, used cases to map UK research excellence in development engineering). Most relevantly though, a BBSRC-commissioned analysis of case studies identified impacts arising from their expenditure on supported projects and programmes (BBSRC 2015). This reported on 642 case studies that have either explicitly referenced the Council as a source of funding, or can be linked to it, or can be associated with it from previous grant funding. From these the Council was able to quantify financial impacts from their investment in research and training over the previous 20 years. In the period 2008-2013 this amounted to £72 billion, arising either from increased output or from cost savings.

This is clearly reminiscent of the widely-reported handsome dividends (Alston *et al*., 2009) discussed in Section 2. It illustrates the perverse tendency of evaluation exercises to select for research that can produce convincing-sounding impacts, whether financial or otherwise. The strength of correlation between that, and authentic impacts from research, is open to question.

5. Be careful what you wish for …

This discussion suggests that there are a number of lessons that need to be learned if the important task of improving agricultural science impact is to be accomplished. In 2009 the novelist Chimamanda Ngozi Adichie gave a celebrated lecture on 'The Danger of a Single Story'[10]. This discussed the appeal of simplifying complexity into a single convincing narrative which confirms prior views, and because it makes sense to those who hear it, provides an impetus to seek confirming evidence for it. The danger of the single story is not that it is untrue; indeed it can be a valid in particular contexts and with appropriate qualifications. Rather, the confirmation bias that it produces leads to disregard of other stories that might have additional, even equal relevance. Conventional wisdom, based on careful and extensive econometric analysis, suggests that the impacts from public agricultural science expenditure pay back stunningly well. However, intuitive scepticism of these claims is reinforced by concerns of policymakers about effectiveness and appropriateness at end-user level. Mainstream economic methods tend to ignore or elide causal processes within the systems they study, which in this case results in lack of focus on the attribution gap between research outcomes and its final impacts. Furthermore, case studies of these impacts tend to explore beneficial impacts, whereas detrimental consequences are much less easy to identify.[11]

[10] https://www.ted.com/talks/chimamanda_adichie_the_danger_of_a_single_story

[11] Possibly this is because, according to Mahoney and Goertz (2006: 240), while it makes sense to include "negative cases and treat them as equally important for drawing conclusions about causal effects … if your

There has been a (partially successful) shift of conception, from the logframe's mechanistic, linear representation of the process of impact generation to a complex, adaptive system of knowledge and innovation where research is one among a number of influential components. This alternative, constructivist approach to evaluation of agricultural science serves a useful heuristic function, but has limited practical relevance for developing an overview of research impact. Tracing out all of the pathways for all projects and programmes would be cumbersome, and difficult to validate.

The impact component of the REF evaluation, as well as contravening all guidelines for use of case studies as a method of inquiry, seems also to have fallen into the trap known as 'Goodhart's Law' (Hoskin 1996). When a measurement becomes a target of policy or management, the behaviour of the underlying phenomenon it is supposed to assess is influenced by the act of measurement, and undergoes a transformative shift. The risk is creation of a compliance culture, biased towards producing an agricultural science with verifiable impacts to perform against a measure, rather than generating new knowledge, and results in an "assumption that the metric *itself* is what matters" (Neylon 2015: 77 – emphasis in original).

Impact evaluation serves several functions. This discussion has concentrated on two main uses, for formative and summative purposes. Both purposes are equally valid, even if the methods used for each are different. The objective in its formative use is to understand how and why scientific research produces, or does not produce, socially desirable impacts. Recognising that it is possible for potential applications of research to be less than fully realised, it seeks to improve the process by which they are taken up, and includes the experiential learning benefits that scientists and other actors in the process may gain. In summative use, the objective is to attribute impacts to research activity and the inputs that supported it responding to the need to demonstrate that societal impacts are indeed important and substantial. It can provide evidence of effectiveness, but is also used as an argument for maintaining or enhancing resources for science. If impacts are not fully appreciated, agricultural science would receive a smaller share of scarce public funding and consequently have less opportunity to produce the aforementioned impacts. The danger, of course, is that because of the attribution gap, the magnitude of impacts is difficult to verify.

Both purposes explore the same questions about what sort of, and how much of, a difference is being made by the original activity. However, to make progress in impact science, especially in application to the important objective of unravelling the population-climate-ecosystem trilemma, more integration is desirable. Econometric analysis should embrace the alternative stories arising from qualitative analysis that cast doubt on the results of the best-fitting models of research impact. Flawed models raise doubts about the validity of inferences drawn from them, even when there is some merit in their overall conclusions. A useful future orientation could go beyond confirmability to explore ways in which proxies for the links from outcomes to impacts could narrow, and ideally close, the attribution gap.

PIPA is chiefly suitable for formative purposes. Even though it extends the focus of analysis beyond outcomes to understand specific impacts from specific projects or programmes, it does not address the overall effectiveness of agricultural science, and fails to satisfy the appetite of policymakers for concise, comprehensive indicators to aid them in decisions about prioritisation of aggregate

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goal is to explain outcomes in particular cases, it does not make sense to select cases without regard for their value on the outcome."

resources. Thus, constructivist approaches to impact evaluation must recognise the pragmatic necessity of convincing funders that relevant societal benefits can be assured and verified. In an analogous field of inquiry, health sciences, summary measures of impacts in the form of Quality Adjusted Life Years (QALYs, and other slick acronyms including DALYs and HALYs; Gold *et al*., 2002), provide a clear and comparable quantitative measure of qualitative facts. A more ambitious approach to identifying and improving the impacts of agricultural science, for instance, could be the projected life of earth and how agricultural science and scientists contribute to its lengthening.

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