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Transformation and slippage in co-production ambitions for global technology development: The case of gene drive

Katie Ledingham *, Sarah Hartley

University of Exeter Business School, Streatham Court, Exeter, EX4 4PU, United Kingdom

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ABSTRACT

Co-production is an increasingly popular framework for knowledge generation, evaluation and decision making. Despite its potential to open up decisions and practices to the input of others, co-production regularly falls short of its transformative ambitions. Through documentary analysis, we investigate the meaning and dynamics of co-production as it stretches beyond the local into global research and technology spaces. We find that in the case of global gene drive, the meaning of co-production is extended in novel ways and underpinned by new possibilities for meaningful transformation. At the same time, we also identify a simultaneous resurfacing of reductive framings of collaboration. In the paper we present 'slippage' as a useful heuristic in helping to understand why co-production fails. We argue that if co-production in these new spaces is to achieve its transformative ambitions, there is a need to engage with new and entrenched knowledge hierarchies that contribute to this slippage.

1. Introduction

Co-production has become a core idea in the theory and practice of sustainability and a powerful framework for knowledge generation, evaluation and decision making (Miller and Wyborn, 2018). Yet, the term has been described as vague and nebulous, encapsulating a broad array of approaches ranging from thin and instrumental consultation, to more robust forms of shared problem definition (Flinders et al., 2016). It has also been criticised for its focus on local projects and scientific knowledge generation, unconnected to broader processes of social change (Norström et al., 2020). In order to realise the transformative potential of co-production, calls are emanating for attention to be paid to the meanings and formatting of co-production in specific contexts (Wyborn et al., 2019). This paper provides insights into the meaning and dynamics of co-production as it stretches beyond the local into global research and technology spaces which typify an increasing number of collaborative projects in the Anthropocene. We are interested in the extent to which the expansion of co-production into these spaces might provide new opportunities for meaningful transformation.

A new and specific form of co-production – co-development – is potentially taking shape in the global governance of gene drive technology. Gene drive is an emerging technology with the potential to address diverse health, environmental and conservation challenges such as the flourishing of invasive species and resurgence of infectious diseases vectored by various species of mosquito (NASEM, 2016; Royal Society, 2018). At present, gene drive is being developed in laboratories in the Global North and through Global North/South partnerships but the first release of a gene drive organism into the environment is expected to take place in the Global South (EFSA Panel on Genetically Modified Organisms (GMO), 2020). Gene drive is a global technology because it is designed to spread through a whole population and will not respect political boundaries. The global nature of the technology combined with its potential to eliminate or alter whole species has resulted in a plethora of governance documents prescribing its responsible development and use. These documents place significant emphasis on a new form of governance emerging under the term 'co-development' (African Union and The New Economic Partnership for Africa's Development (A.U. and NEPAD) (2018); Hartley et al., 2019; James and Tountas, 2018).

We employ a nascent theory approach to analyse co-development through performative documents attempting to define the terms of collaborative practice (Edmondson and McManus, 2007). Nascent theory involves inductive learning in cases where there is little explication of the construct or process under study. We document the emergence of a knowledge co-production approach in gene drive research and development and reveal four key ambitions: 1] collaborating with communities, stakeholders and publics; 2] building capacity; 3] engaging with social-cultural contexts, and; 4] embracing

* Corresponding author.
E-mail addresses: k.a.ledingham@exeter.ac.uk (K. Ledingham), Sarah.Hartley@exeter.ac.uk (S. Hartley).

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environmental complexity. These ambitions present new opportunities for realising co-production's transformative ideals, but each ambition is accompanied by a resurfacing of top-down hierarchical governance approaches. We argue that slippage is a useful heuristic to understand why co-production fails and demonstrate that, in the case of gene drive, such slippage can be linked, in part, to the persistence of entrenched as well as new knowledge hierarchies. In order to advance the theory of co-production and realise its transformative potential, attention needs to focus more squarely on what van der Hel (2016) describes as the gap between inclusivity and transformation where slippage plays a role.

2. Meanings of co-production across borders

Co-production has a rich history spanning multiple disciplines and epistemic traditions (Miller and Wyborn, 2018). It involves opening up decisions and practices to the input of others in order to generate more equitable and innovative sustainability outcomes (Lemos and Morehouse, 2005). It also involves recognising that framings and practices of science, nature and policy are mediated or co-produced by social relations (Jasanoff, 2004; Jasanoff and Kim, 2015). Jasanoff (2005: 3) points to the importance of 'culture, values, subjectivity, emotions and politics' in co-producing socio-technical orders. As a call for greater participation in science and technology decision making, co-production is underpinned by normative arguments that shared decision-making is ethically superior as well as by the recognition that collaboration can increase social resilience and empower marginalised voices (Filipe et al., 2017; Glasbergen, 2011). It is also premised upon the recognition that epistemic diversity can contribute to the generation of more robust innovations and policy interventions. Scientific research is currently enjoying a renewed prescription for co-production, with advice on how scientists can take a more co-productive approach to their research appearing in eminent journals such as *Nature* (cf Vera, 2018; Norström et al., 2020).

However, despite the great gusto for co-production, two dominant challenges exist in the literature. First, co-production is subject to considerable interpretive flexibility and degrees of influence. Co-production is imagined and practiced in highly variable ways (Norström et al., 2020). Flinders et al. (2016) suggest co-production is subject to conceptual stretching, arguing that it has different 'shades' that run from thin, instrumental shades, to deeper shades where co-production becomes embedded and meaningful. van der Hel (2016) notes a similar distinction. This heterogeneity in meanings is confusing in both theory and practice. Wyborn et al. (2019) call for a robust discussion about what co-production practices and processes are appropriate and effective and in what contexts. To achieve this kind of discussion, more attention must be paid the meanings of co-production and how these meanings matter for co-production's transformative potential.

The second challenge is concerned with co-production in different contexts. Too often, studies of co-production are focused on a specific local or regional context and on the generation of scientific knowledge (Miller and Wyborn, 2018). However, global research partnerships and cross-border collaborations are increasingly prevalent ways of addressing global sustainability challenges (Chu et al., 2014; Larkan et al., 2016). Further, research institutions, funders and non-governmental organisations increasingly operate at a global scale (Norström et al., 2020). Turnhout et al. (2020) suggest that in these global contexts, co-production may need to address pronounced inequalities and power imbalances. For example, Chu et al. (2014) have argued that capacity building in the Global South may help to maximise the benefits of co-production when these power imbalances exist. This paper addresses these challenges through an examination of the meaning of co-production in the development of an emerging global technology that crosses international borders. We are interested in what happens to co-production when it stretches into these global spaces which entangle multiple countries, relations and actors in new ways.

3. Methodology

3.1. The case study

Gene drive is a prominent case through which to conceptually develop our thinking on co-production in global spaces (Flyvbjerg, 2006). Gene drive is a natural process identified by Austin Burt in 2003. Burt identified selfish genetic elements which increase the propensity of a particular gene to be preferentially passed on to an offspring organism (Burt, 2003). The power of selfish genetics lay dormant until the development of genome editing tools such as CRISPR Cas9 which enable scientists to direct this process for human ends. By 2014, scientists were able to 'drive' desired traits through offspring populations by altering the genome of an organism (such as a rat or mosquito) so that it expresses a particular trait (e.g. refractoriness to disease or altered reproductive capacity). This 'synthetic' drive allows scientists to bypass Mendelian rules of inheritance and force edited genomic changes through a whole species (Gantz and Bier, 2015). Unlike genetically modified organisms developed under conditions of contained use, gene drives are intended to propagate within ecological systems.

Gene drive developers claim the technology has huge potential to address a diverse array of contemporary health and environmental challenges (Hammond and Galizi, 2017; Webber et al., 2015). The technology is currently being developed by a small number of scientists supported by public, private and philanthropic funders including the Bill and Melinda Gates Foundation and the Defense Advanced Research Projects Agency, a US agency responsible for emerging technologies for military use. As the technology develops, new applications are emerging including the control of invasive species flourishing under changing climatic conditions, such as rodents and flies (NASEM, 2016). The gene drive application which scientists expect to be deployed first is Target Malaria's gene drive mosquito (EFSA Panel on GMO, 2020). These mosquitoes are modified through a 'suppression' drive system involving genes that reduce female fertility and bias the sex ratio to reduce or 'supress' the population of biting female mosquitoes (Target Malaria, 2019).

International tensions surrounding the development of gene drive were apparent at the recent 2018 Convention on Biological Diversity in Sharm El Sheikh, Egypt where civil society groups made calls for a moratorium on the future use and development of the technology (Callaway, 2018). These calls expose normative questions about the procedures that will be used to make decisions about gene drive deployment and are one of the drivers of a co-production approach.

3.2. Data collection and analysis

The theoretical basis of this paper interweaves co-production and nascent theory, allowing us to be 'guided by and open to emergent themes and issues' related to the emergence of the new term, co-development (Edmondson and McManus, 2007, p.1164). This means that while the analysis process is alert to argumentation already established in co-production literature, particularly surrounding the meanings and interpretations of co-production, it will also be attentive to the specificities of the data. There has been little delineation of the dynamics and meaning of co-production as it stretches into increasingly global research and technology spaces, making nascent theory a key departure point for the paper. Co-development emerged in high-level governance documents prescribing a co-production approach to the development and deployment of gene drive. Using qualitative documentary analysis we took a broad understanding of what co-development means, mapping over time the solidification of a model that was taking shape as early as 2014. Data sources were collected and analysed between 2017 and 2019 (Table 1). To meet criteria for inclusion they needed to be written by four or more gene drive funders, supporters and developers and with an aim to establish a benchmark to shape practice. Our inclusion criteria resulted in documents such as the 2018 'A Constitutional

Table 1
Data set of gene drive governance documents*.

D1	Year: 2019	Title: Sustainable innovation in vector control requires strong partnerships with communities
	Author/s: Bartemus et al	
D2	Year: 2019	Title: Guidance on stakeholder engagement practices to inform the development of area-wide vector control methods
	Author/s: Thizy et al	
D3	Year: 2018	Title: Gene drives for malaria control and elimination in Africa
	Author/s: AU and NEPAD	
D4	Year: 2018	Title: Pathway to the deployment of gene drive mosquitoes as a potential biocontrol tool for elimination of malaria in sub-Saharan Africa: recommendations of a scientific working group
	Author/s: James et al	
D5	Year: 2017	Title: Results from workshop 'problem formulation for the use of gene drive in mosquitoes'
	Author/s: Roberts et al	
D6	Year: 2017	Title: Principles for gene drive research
	Author/s: Emerson et al	
D7	Year: 2016	Title: Gene Drives on the Horizon: Advancing Science, Navigating Uncertainty and Aligning Research with Public Values
	Author/s: NASEM	
D8	Year: 2016	Title: Policy and regulatory issues for gene drive insects
	Author/s: Carter and Friedman	
D9	Year: 2014	Title: Guidance framework for testing of genetically modified mosquitoes
	Author/s: WHO	

* Full citations in end reference list.

Moment – Gene Drive and International Governance' report by the Sustainability Council of New Zealand being excluded from our analysis. We also excluded documents with a narrow focus on risk assessment or the development of principles for community consent. Our data set reflects the advanced development of gene drive applications in global health, particularly the gene drive mosquito for malaria control, over other applications such as the gene drive mouse for conservation (e.g. Farooque et al., 2019). Our selection resulted in the following documents intending to set benchmarks for collaborative practice (Table 1).

Using a discourse analysis approach we investigate the meaning of co-development and how it is conceptualised as a driver of more effective and equitable approaches to the development of a technology with global reach. Analysis proceeded through a three-step process. An iterative re-reading of the governance documents led to the identification of first order information-based codes. First order codes reflect key topics and themes within the documents (Pansera and Owen, 2018). These codes were then assembled into second order, theory centric codes denoting broader thematic categories. Finally, we developed aggregate codes encapsulating the second order theory centric headings. The coding and analysis process required us to be 'guided by and open to emergent themes and issues' (Edmondson and McManus, 2007: 164). Our methodological approach recognises the value of a case study contribution, yet speaks back to theory development through its investigation of the formatting of co-production in a new problem space (Flyvbjerg, 2006; Sovacool et al., 2018).

4. Results

4.1. Co-development as a new form of co-production

A new sub category of co-production - co-development - emerged within key governance documents responding to the science of gene drive between 2014 and 2019. As early as 2014, the scientific community and international governance institutions were alert to the need to ensure gene drive development and governance was conducted in an open, transparent and collaborative fashion. The World Health Organization (2014) *Guidance Framework for the Testing of Genetically Modified Mosquitoes* was the first to emphasise the importance of a 'democratic' approach. Recognising a 'new era of science' typified by heighted public awareness and scrutiny of science, the framework stressed that gene drive research must be conducted in an engaged manner (World Health Organization, 2014: 71).

By 2015, scientific capabilities began to develop rapidly and proof of concept drives were developed in yeast, fruit flies and mosquitos (NASEM, 2016). Later that year, the J. Craig Venter Institute, a world-leading genomics research centre, published *'Policy and Regulatory Issues for Gene Drives in Insects.'* The report argued gene drive developers have a greater responsibility to pursue social acceptance of the technology beyond regulatory approval due to the propensity of gene drives to interact with and persist in the environment.

Also in 2015, the National Academies of Science, Engineering and Medicine (NASEM) convened an expert group to develop a coherent response from the scientific community. The expert group, composed of 16 members with interdisciplinary expertise across the natural and social sciences, developed a 'consensus overview' of the state of the science and expectations for responsible research. Its report *'Gene Drives on the Horizon: Advancing Science, Navigating Uncertainty, and Aligning Research with Public Values'*, recognised the capacity of gene drive to 'genetically alter a wild population, and potentially an entire species,' represented a unique governance challenge (NASEM, 2016: 70). It emphasised engagement, stipulating that the participation of stakeholders, publics and communities will be as important as the science if gene drive is to progress beyond the laboratory and fulfil its potential.

By 2017, it became apparent that the first application of gene drive technology was likely to be gene drive mosquitoes to reduce malaria in sub-Saharan Africa. In 2019, Target Malaria released genetically modified sterile male mosquitoes in Burkina Faso in order to develop knowledge and capacity for the proposed release of gene drive mosquitoes. This advance led gene drive funders and supporters to establish a funder forum, providing an avenue for funders and stakeholders to review developments in the field and to coordinate work streams to 'move the field forward in a positive manner' (FNIH, 2017: para.1). As part of this reflexive practice, representatives from the Wellcome Trust, the Foundation for the National Institutes of Health and the Bill and Melinda Gates Foundation published *'Principles for gene drive research'* in the journal *Science*, calling for a culture of responsible innovation in gene drive development and deployment (Emerson et al., 2017).

Later in 2018, the publication of '*Pathway to Deployment of Gene Drive Mosquitoes as a Potential Biocontrol Tool for Elimination of Malaria in Sub-Saharan Africa: Recommendations of a Scientific Working Group'* constituted a high profile attempt to develop a practicable plan of action. A strong commitment to collaboration had at this stage begun to solidify under the auspices of the term 'co-development'. The Pathway document stipulated that 'Scientists and research institutions in the countries where the product ultimately will be used must play a central role in the development process from its early stages' (James et al., 2018, p.20) and that development and deployment of gene drive must involve 'interaction with a diverse spectrum of groups' (James et al., 2018: 9).

There was now resounding recognition that gene drive posed notable scientific, ethical and governance challenges and calls for collaboration began to be heard from experts in Global South countries who would be expected to host the first field trials of gene drive organisms. In 2018, Dr Jonathon Kayondo of Uganda Virus Research Institute stated:

'Africa must not wait for advances in malaria innovation – we must pioneer them - to position ourselves at the forefront and spur development of this new field, we need African and Africa-based scientists to add their voices to the debate on genetic technologies, which have so far taken place largely in Europe and North America.' (Kayondo, 2018: para.12)

The 2018 African Union and New Economic Partnership for Africa's Development report *'Gene Drives for Malaria Control and Elimination in Africa,'* also emphasised the importance of the term co-development which it described as being based on 'collaboration between the partners in the teams, from research design to the creation of standard operating procedures' (African Union and The New Economic Partnership for Africa's Development (A.U. and NEPAD) (2018), p.13). Later in 2019, the '*Guidance on Stakeholder Engagement Practices To Inform the Development of Area-Wide Vector Control Methods*' defined co-development as 'A collaborative process of jointly designing a research pathway and its resultant intervention to reach a common goal' (Thizy et al., 2019: 4). This document stressed that an effective co-development approach will require 'dialogue and compromise,' acknowledging that redefinition of project goals may also be required (Ibid). In the analysis and discussion that follows, we unpack the meaning co-development and investigate its ambitions.

4.2. An anatomy of co-development's transformative ambitions

Our inductive approach to data analysis reveals four transformative ambitions for co-development: (1) collaborating with communities, stakeholders and publics; (2) building capacity; (3) engaging with social-cultural contexts and (4) embracing environmental complexity. We explore these ambitions, how they embody the open and transformative aspects of co-production, and show where these ambitions 'slip' back towards what van der Hel (2016) describes as linear, mono-disciplinary research models and the traditional hierarchal structures and assumptions that accompany them. Table 2 summarises these ambitions and their slippage.

4.2.1. Collaborating with communities, stakeholders and publics

Engagement with communities, stakeholders and publics is positioned as an essential component of gene drive development. Strong calls are made for funders to allocate a percentage of technical grants to engagement activities. There is a clear and expressed commitment to 'meaningful' engagement that embodies 'respectful listening, creative compromise, and flexible practice' (D7: 134). WHO emphasises that engagement activities should not be conceptualised in terms of an education or deficit model, insisting that well-developed engagement can help direct technical goals, improve the performance of research in social contexts and generate new learning opportunities. As WHO explains, scientists 'have become cognizant of new ways that involving non-scientists in their work can be beneficial. Exceedingly complex problems may require planned activities that engage non-scientists in collaborative or problem-solving roles, rather than considering them solely as subjects' (D9: 71).

Table 2
An anatomy of co-development.

Collaborating with communities, stakeholders and publics	Building capacity	Foregrounding social-cultural contexts	Embracing environmental complexity
	Ambition		
Communities, stakeholders and publics to contribute substantive knowledge to the technology's development through engagement	Host country partners empowered to develop and scrutinise the technology	Social-cultural values and practices to shape technology pathways and risk assessment	Environmental complexity necessitates experimental methods and diverse knowledge
	Slippage		
Community, stakeholder and public engagement to secure acceptability and delimit criticism	Capacity building to ensure the scientific and technical capabilities exist to facilitate pre-defined developmental pathways for gene drive	Social-cultural context is a barrier to be overcome to develop and deploy gene drive in the Global South	Environmental complexity to be managed through expert-led risk assessment and quantifiable parameters

NASEM similarly builds upon the substantive type of engagement articulated by WHO, emphasising that engagement with communities, stakeholders and publics is 'critical for successful decision making regarding the research, development and potential release of gene drive mosquitoes' (D7: 131). NASEM contains one of the most comprehensive discussion of engagement in gene drive to date, calling for a 'meaningful' and 'robust' approach. It differentiates itself from customary mechanisms of engagement existing under the provisions of the US National Protection Act which stipulates that the public must be notified prior to the release of a GMO. NASEM states public notice is an 'inadequate platform for the more robust forms of engagement' needed (D7: 171).

Risk and hazard assessment is a key area where engagement is identified as being able to substantively contribute to gene drive decision making. NASEM notes community engagement may help to provide 'critical insights about potential harms' (D7: 78). AU and NEPAD similarly note 'researchers and risk assessors should integrate engagement into the construction of risk assessment models' (D3: 21). Both WHO and NASEM highlight the innovative approach to engagement surrounding the risk assessment and release of mosquitoes infected with the Wolbachia bacterium in Cairns, Australia. Populations living at the release site were engaged in ways which generated new research questions including whether or not Wolbachia could be passed on to humans through the salivary glands of mosquitoes. Engagement here provided a means of reconfiguring the research programme.

Engagement has an important role to play in cultivating new relationships and socialities - it can contribute more broadly to innovation in the opening up of reflexive deliberation surrounding societal futures, values and modes of organisation (including funding priorities) (Buchthal et al., 2019; Delborne et al., 2017; Farooque et al., 2019; Lemos and Morehouse, 2005). Yet, beyond identifying harms it is not clear from the documents how knowledge gathered through engagement might shape the technology trajectory in other ways. Aside from the identification of environmental hazards, discussions slip back regularly to information dissemination models foregrounding the need to 'convey intelligible information about gene drive' (D7: 136). While the documents recognise there are different types of publics and that engagement is multifaceted (D2, D4, D7), there is a lack of clarity surrounding the role and potential contributions of these groups. Non-expert publics are regularly described as having 'perspectives' rather than knowledge (D9: p.vii; D7: 136; D4: 28) and slippage is further evidenced by the temporality of accounts of engagement which describe engagement as enabling communities to participate in decision making about the *use* (rather than the design and development) of gene drive organisms (D7: 80).

4.2.2. Building capacity

Capacity building is regarded as a transformative component of co-development, empowering Global South actors to draw on their own 'values rather than relying on values imported from elsewhere' (D7: 77). James et al. call for emphasis to be placed 'not only on technology transfer to partner institutions, but on building knowledge about gene drive technology among African scientists and the public more broadly' (D4:41). NASEM espouses similar sentiment, emphasising the 'ability of people in low-income countries to participate meaningfully in decision making would be supported best not by merely engaging them in decision making but by building the capacity in those countries to conduct research that is locally valuable' (D7: 76–77).

Here, the focus is on ensuring Global South research partners are able to become developers and scrutinise technology trajectories. As WHO emphasises, Global South decision-making bodies should have 'the capacity to formulate the risk problem, to define appropriate endpoints for risk, [and] to interpret the character of the component sources of risks' (D9: 62). Capacity building is envisaged through a number of practices and protocols. The documents stipulate scientists from Global South institutions should be able to participate in research and safety work conducted in the Global North (D7, D2). WHO regards these opportunities as laying a foundation for 'future strength and independence for national research activities' (D9: 34).

Yet, it is not clear in practice how capacity building might be extended in a way that benefits a wider constituency of publics beyond natural scientists and field entomologists. The focus is on ensuring Global South partners have the infrastructure and regulatory mechanisms in place to 'support trials, including an experienced team of entomologists and epidemiologists, and the capacity for transport, sample collection, and laboratory work' (D4: 21). Minimal mention is made of capacity building in areas such as the social sciences or humanities.

There is recognition of the need for 'independent' social inquiry into the conditions for effective community participation (D1: 3). Yet, there is no attempt to build capacity in understandings surrounding how the reconfiguration or 'cessation' of a project (D2) could generate beneficial outcomes for all including for technology developers. Where capacity is mentioned it is often linked to the capacity of developers to engage in dialogue with stakeholders, rather than the capacity of multiple publics to open up the technology trajectory through deliberation (D2).

The emphasis on building capacity to support field trials and regulatory infrastructures reveals a prevalent instrumental rationale driving capacity building that resembles business-as-usual and conflicts with the described transformative ambitions. The technology is ultimately being developed in the Global North with deployment capacities enhanced and developed in the Global South. However, global health and development literatures suggest capacity building can be conceived in substantive rather than instrumental ways (Fransman et al., 2019; Kok et al., 2017; Madsen and Adriansen, 2020).

4.2.3. Foregrounding social-cultural contexts

All governance documents recognise that engaging with social-cultural contexts is fundamental to co-development of the technology. There is an acknowledgement that terms such as 'species diversity' and 'ecosystem health' are contingent descriptions imbued with social values and judgements (D7: 116). NASEM notes that while *Palmer amaranth* is regarded as a weed and target for gene drive in the United States, related species of *amaranth* are cultivated for food in Mexico, South America, India and China where they hold social-cultural significance (D7: 68). Roberts et al. similarly emphasise that any definition of biodiversity risk 'is dependent on identification of what aspects of biodiversity are considered valuable' (D5: 532). The documents call for social-cultural values to be built into environmental protection goals (D4-D5, D7).

As well as acknowledging diversity in social-cultural values, there is an alertness to prior experiences in global health where social-cultural contexts were not fully appreciated or engaged. NASEM makes reference to the poor uptake of functionally efficient and effective bed nets for malaria control in Kenya where the white nets 'mimicked the burial shrouds used by the local population, who thus did not adopt them' (D7: 133). The WHO recounts a prior historical incident in India where a WHO van bearing a snake logo released cases of sterile male mosquitoes into a local community. The villagers who had a fear of snakes regarded the van suspiciously and reacted angrily to the release (D9: 86). These instances contribute to the call by James et al. for technology development programmes to investigate 'local social and cultural perspectives on biotechnology research, malaria eradication, and large-scale public health efforts' (D4: 21).

The literature suggests that the social-cultural context of science and technology cannot be separated from facts and objectivity in co-production (Jasanoff, 2004). Further, this social-cultural context allows for the production of new types of knowledge which may suggest meaningful ways to solve societal challenges (Filipe et al., 2017; Leach and Scoones, 2006). Yet, while the documents evidence learning, it is notable that the overarching rationale for engaging with social-cultural contexts is to determine potential barriers to the deployment of gene drive technology. NASEM describes how engaging with publics is 'complicated' (D7: 79) by variations in risk perceptions and that cultural distrust of GM crops may encourage similar distrust in gene drives. This requires being 'wary about any one way of framing gene drive technology (D7: 80). While WHO is wary of assuming one decision maker is representative of whole community, there is no delineation of how a broader remit of publics might be engaged (D9). There is also little clarity on the methods required to effectively develop an appreciation of social-cultural values and knowledges. Incorporating social-cultural values into environmental protection goals in a meaningful way will require public deliberations. There is little discussion of what this might look like and the resources this might require in the documents.

4.2.4. Embracing environmental complexity

The documents show a strong ambition to respect the natural world as a collaborator in the technology development process. This marks a departure from prior technocentric approaches, which regard the natural environment a passive subject without its own agency. NASEM is cognisant of limits in the capacities of scientific knowledge to predict the unfolding of gene drive in ecological systems, acknowledging that laboratory settings cannot fully replicate environmental conditions and that proof of concept studies conducted in the laboratory are insufficient to 'support the release of gene-drive modified organisms into the environment' (D7: 177). James et al. similarly stipulate that some questions about safety 'may not be answerable by laboratory studies and modelling' (D4: 15). The documents acknowledge the importance of not shying away from 'uncertainty of outcomes and risks' (D2: 8) and that research must be conducted with 'respect and humility for the broader ecosystem in which humans live' (D6: 1136).

Proposed responses to the off-target effects and potential unintended consequences include the regular sampling of gene drive organisms and wild strains to detect the emergence of resistance. In NASEM, 'reversal' and 'immunisation' drives intended to destroy the original drive are recommended. Yet, NASEM recognises the limits of applying engineering logics to living materials, emphasising that it is hard to predict the effects which might arise 'the creation of breaks in DNA' (D7: 98). NASEM also recognises that the use of assays (biological monitoring used to monitor resistance) can contain inbuilt assumptions which can lead to 'observational bias' (D7: 98). Ecological risk assessment is also proposed as a response to environmental complexity (D4-D7) and positioned as a more robust alternative to environmental assessments (D7). Ecological risk assessment is defined as being alert to multiple interacting stressors. This described as necessitating 'convergence of multiple fields of study including molecular biology, genome editing, population genetics, evolutionary biology, and ecology' (D7: 7) as well as public engagement.

Yet while ecological risk attempts to grapple with the complexity of processual systems, it regularly falls back on reductive models more akin to conventional risk assessment methods. For example, NASEM suggests it will be important for ecological risk assessment to identify cause-effect pathways in a probabilistic manner (D7: 204). Complex process cannot always be identified in this way (Stirling, 2010). Across the documents (D1-D9) there is also little delineation of the types and kinds of long term experimental sampling methods needed to identify unanticipated unintended effects. Taking seriously the systems complexity of gene drive will require experimental methods over long time periods of time. Enrolling the environment as a collaborator requires not only recognising that environmental systems are understood differently by different epistemic traditions (as evidenced in Section 4.2.3) but also taking seriously the propensity of non-human systems and organisms to exceed human models and frames of reference (Bennett, 2009; Dürbeck et al., 2015).

5. Discussion

Norström et al. (2020) argue that the stretching of co-production into new spaces may provide opportunities for co-production to realise its transformative ambitions. We found this to be true in our case. The global nature of our case, as well as the transformational nature of the technology, has stretched co-production in ways which enhance its potential for meaningful change. It is not simply stakeholders and communities that are recognised as collaborators in the technology development process. Non-human actors (including genes and ecologies) are also recognised for their role in shaping technological outcomes. This is a key addition to the theory and practice of co-production. As environmental philosophers have long argued, plants, genes and ecologies do not simply conform to scripts that we give them (Bennett, 2010). Recognising non-human agencies with humility is key to developing robust environmental sustainability outcomes. Co-production has also been broadened in our case through its emphasis on capacity building. Capacity building has potential to rebalance power inequalities and may help to connect co-production to border processes of social change.

Yet, perhaps the key finding to emerge from our analysis is the identification of an uneasy co-existence between an ambitious commitment to meaningful change and a simultaneous resurfacing of linear, mono-disciplinary models of collaboration (van der Hel, 2016). While the governance documents articulate a concerted effort to developing more equitable forms of science and technology this commitment is regularly muddled along the way. We propose that 'slippage' is a useful heuristic in helping to make sense of the simultaneous co-existence of competing framings in this context. As theoretical attention increasingly begins turns towards the reasons why co-production fails (Turnohut et al., 2020), slippage encourages us to focus on why co-production might fall short. It contributes to theory building efforts by drawing attention to the discourses, process and contexts that contribute to the gap between inclusivity and transformation.

Slippage appeared across each of the four ambitions of co-development. Indeed, despite the ambitious commitment to inclusivity and collaboration broadly defined, there is an overarching emphasis on engagement with communities in order to obtain consent for future field trials. The dominant strategy is a conventional model of establishing community trust, understanding perceptions and securing acceptance for the technology. This provides only minimal opportunities for the technology to be opened up to alternative trajectories and knowledges.

Similar challenges are also evident in capacity building which is imagined in narrow scientific spaces designed to enhance deployment capabilities in support of pre-determined trajectories. If capacity building is to contribute to a transformative form of co-production, it must empower a much broader range of disciplinary and professional capacities including social science and engagement capacities within the Global South to facilitate the opening up of technology futures to multiple visions and publics. Otherwise this approach to capacity building more closely resembles neo-colonial research models as well as the privileging of science over other forms of knowledge (Beran et al., 2017). Slippage also appeared in the third and fourth ambitions of co-development, where social-cultural contexts were regarded as barriers to the deployment of the technology and a commitment to embracing environmental complexity fell back on a reductive risk assessment approach.

Slippage can be linked to the persistence of new and emergent knowledge hierarchies. These are expert-lay hierarchies and expert-expert hierarchies. The privileging of expert over lay knowledge is well-documented in the literature (Seethaler et al., 2019) and remains entrenched in our case. The gene drive governance documents largely presume knowledge is to flow from experts to publics and make no substantive attempt to outline how knowledge might flow the other way. Other than attempting to elicit concerns or risks associated with a pre-determined technology trajectory, there is little imagination surrounding how other knowledges might flow back into the technology problem space in substantive ways. This is despite long-standing developments in fields such as science and technology studies (STS) which demonstrate that expertise is distributed and that 'non-expert' publics can provide substantive insights into scientific problems (Callon et al., 2011). While recent calls to enrol local publics into entomological surveillance attempts in novel ways may generate new socialities and learning opportunities (Thizy et al., 2019), the emphasis is nevertheless still largely on educating communities rather than opening up fundamental questions surrounding the kinds of technology futures and the kinds and qualities of relationships between technology developers, organisations and publics that we might want to bring into the world.

The second knowledge hierarchy, an expert-expert hierarchy in which certain types of science and expertise are privileged over others, is less explored in the existing co-production literature. In particular, we observe the privileging of natural scientific knowledge over both social science knowledge and practitioner knowledge. African scientists have called attention to the expert-expert knowledge hierarchy, pointing to the privileging of Northern expert knowledge and calling for African involvement in gene drive development (Mshinda et al., 2004; Kayondo, 2018). The former Minister of Health in the Republic of Namibia, Richard Kamwi, has argued that the knowledge and perspectives of representatives from malaria-afflicted countries are missing from conversations about gene drive development (Kamwi, 2016). Hassan Mshinda (Mshinda et al., 2004: 264), director general of the Tanzania Commission for Science and Technology suggests that ecological studies and field research constitute 'an immediate opportunity for malaria-afflicted nations to regain their roles as stakeholders, decision makers, and eventual owners of this technology.'

Realising the transformative potential of co-production will require redressing these imbalances in knowledge. It will also require the development of processes, practical tools and theoretical insights that can help to prevent slippage towards traditional hierarchical models. Elsewhere we have argued that thinking in terms of 'knowledge engagement' rather than 'public engagement' can help to focus attention on the direction of knowledge flows, thereby preventing slippage towards one way information dissemination, or knowledge deficit models (Hartley et al., 2019). A knowledge engagement lens can help to provoke reflexivity, making visible engagement practices where it is presumed, for example, that scientists hold a monopoly on expert knowledge. Knowledge engagement can also contribute to the development a clear articulation of the diverse contributions that can be made by multiple epistemic traditions. This will be key in moving beyond expert hierarchies which are based upon presumptions which regard the role of the social sciences as existing to communicate to publics or identify public perceptions which might disrupt technology trajectories (Balmer et al., 2015).

As well as addressing new and emerging knowledge hierarchies, it will also be critical to think about which actors are shaping the terms of the debate. The shift from government to distributed governance, which has been drive in part by the complexity of global challenge issues, has been accompanied by a reduction in the role of state actors (Ansell and Torfing, 2016). In our case, the retrenchment of state actors resulted in a relatively narrow group of funders, technology developers and high profile organisations with an interest in the deployment of the technology shaping the terms and framing of collaboration. There is a danger that unless mechanisms are put in place to address slippage in co-development, it may be perceived as an instrumental tool designed to push through a technology under the illusion of participation, particularly where elite groups are involved.

6. Conclusion

The case of the co-development of gene drive raises important lessons for the theory and practice of co-production as it stretches into new global spaces. The global nature of our case as well and the transformational nature of the technology stretched co-production in ways that enhance its potential for meaningful change. Co-development is attentive towards the agencies of the natural environment and alert to the need to engage in capacity building to shift collaboration from discourse to praxis. Yet, at the same time, we have also identified an uneasy co-existence of transformational and reductive framings of collaboration in co-development. Slippage is a useful heuristic to help researchers make sense of tensions between inclusivity and transformation, particularly as collaborative governance moves into new spaces extending beyond local scientific knowledge generation projects. Slippage in co-development of gene drive can be linked to the persistence of established knowledge hierarchies between expert and lay publics as well as new hierarchies between expert traditions. Redressing shortcomings in co-production will require sustained theoretical delineation into these kinds of reasons why co-production fails. Our case sheds light on the new and entrenched hierarchies that will need to be addressed if co-production is to achieve its transformative ambitions.

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Declaration of Competing Interest

None.

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