Australian Academy of Science

AN INTERDISCIPLINARY APPROACH TO

LIVING IN A RISKY WORLD

RECOMMENDATIONS

from the 2016 Theo Murphy High Flyers Think Tank

CONTENTS

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FOREWORD

We humans have always lived with risk. On one level, we are fortunate to live in a safer, less risky world now compared to that of our ancestors, which can be seen simply by looking at human life expectancy through the ages. Our senses are limited and we have never had a 'complete' picture of our surroundings, yet we nonetheless thrived. Our evolution as a species primed us very well to conservatively assess and react to certain types of risk, primarily those relating to life and limb, yet those selection pressures are thankfully not as urgent in our modern lives. Psychology literature shows that our subjective judgements of—and responses to—risks are not well calibrated with either the likelihood or consequence of certain types of threats or hazards, and that our intuitive human responses are resistant to change through the mere knowledge of facts.

Many of the risks that face us today are far more complex in nature than those our ancestors faced, which calls for a more thorough examination of the science underpinning the issues that pose modern risks. The examples summarised in this report highlight just how important it is to bring scientific evidence and rational planning to bear on modern problems that require more than our basic human instincts have prepared us for. For example, we need excellent science coupled with evidence-based public policy to overcome the challenges posed by both antimicrobial resistance and long-term environmental change.

It is important that as a society we view risk and uncertainty as neutral: neither inherently good nor bad. Risk is as much about opportunity as it is about avoiding bad things: uncertainty is as much a signpost towards new discovery and understanding as it is about simply not knowing. Carefully considering both can help us make decisions that will secure the best possible outcomes for Australia. The recommendations in this report provide ways in which decision makers, the public and researchers can act in accordance with an understanding of risk and uncertainty to inform the direction of Australia's future.

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President, Australian Academy of Science

EXECUTIVE SUMMARY

We all live in a risky world. We face risks every day—unknown (usually unfavourable) events, but about which we have an idea of their probability. For example, when taking a plane we know we run the risk of our flight being delayed. Uncertainty on the other hand is an unknown event with an unknown probability. This is when we don't know what the possible outcomes of a situation are or how likely they are to occur. The desire to avoid risk and reduce uncertainty seem to be innate in all human societies—yet people are generally poor at estimating and responding to risk and uncertainty in their daily lives. For example, many people feel safer driving between major cities rather than flying despite the former involving much greater risks.

Mathematicians, economists, engineers and others have developed a multitude of tools to assist with decision-making under uncertainty across a broad range of contexts and professions. These tools are useful for those who make decisions in our society that are based in whole or part on evidence. However it is important to consider the context within which these tools are used. For example, how well does the decision-maker understand the evidence or the tools used to create it? How good are the scientists at communicating the details of the tools and the evidence? How do we decide which tools are the best to apply to this decision?

A two-day event, the *2016 Theo Murphy High Flyers Think Tank: An interdisciplinary approach to living in a risky world*, aimed to assess, understand and address how questions like these impact on how risk and uncertainty affect decision-making. To achieve this the Think Tank brought together early- and mid-career researchers from a broad range of disciplines across science, social science and the humanities. They developed a number of recommendations for scientists, the public and decision-makers regarding how to understand, communicate, assess, and deal with risk and uncertainty. They also examined three major areas where Australian decision-makers grapple with risk and uncertainty: allocation of resources to environmental projects, international security, and responding to antimicrobial resistance. They developed recommendations on what the important risks in these areas were and offered strategies to address them.

SUMMARY OF RECOMMENDATIONS

Addressing risk in conditions of uncertainty, ignorance and partial knowledge

In order to improve evidence-based decision-making we need to develop **a better understanding of how uncertainty affects decision-making**. This would be achieved by gathering case studies from both scientists and decision-makers, and forming networks between the two groups. This interdisciplinary research would form the basis of **improved communication of risk and uncertainty between scientists, decision-makers and the general public**. Guidelines on how to report risk and uncertainty should be developed and a common language to discuss them should be built. In addition, communication training for scientists would help improve understanding, as would standardising the pathways through which scientists can communicate with decision-makers.

Risk and resource allocation in the environment

Cost-benefit analysis (CBA) is one of the main tools used by decision-makers to assess and prioritise potential projects. However there are some recognised difficulties with its application to environmental projects, where an economic value can be difficult to assign to environmental outcomes. To improve the application of CBA in the context of environmental policy, all levels of government should **publish all CBA models and their associated data used in decision-making** to ensure transparency and accountability. Best practice could be achieved by **developing national CBA guidelines for environmental projects**. In addition, it should be recognised that most environmental projects are comprised of sequential decisions made over time, and tools which help to account for uncertainty in this process should be incorporated into the process. Many benefits associated with environmental projects are **non-monetary benefits and these should accounted for appropriately**.

Risk in international security

Australia could take a leading role globally in addressing risks relating to disruptive technologies, global migration flows and environmental change. Creating an **effective policy–research collaboration** would allow Australia to respond to disruptive technologies. The collaboration should include structures that identify and inform research priorities and undertake regular reviews to keep pace with changes to technologies. Regarding global migration flows, Australia should act humanely and justly to bring its domestic law, policy and practice into accordance with international obligations. Promoting interdisciplinary **research into how migrants and destination communities can effectively manage rapid and unplanned change** would assist Australia to balance concerns for security with social implications for individuals and communities. Finally, Australia could respond to the risks associated with environmental change by instituting stable governance structures to provide scientific advice and **developing evidence-based science communication strategies** which explain environmental risks to the community.

Antimicrobial resistance: A complex multi-factorial problem requiring an orchestrated interdisciplinary response

Microorganisms that cause infections in humans are increasingly becoming resistant to the antimicrobial drugs which we use to treat infections. This is a 'One Health' problem: a problem that affects human, animal and environmental health. To accelerate some of the existing common objectives to address antimicrobial resistance, **interdisciplinary research** in the field, including **socio-cultural and behavioural research**, would help engage with stakeholders and inform best practice strategies. A knowledge gap exists surrounding the **impact of gene reservoirs in the environment** and research is required to guide processes for waste management. Finally, **antimicrobial use should be incorporated into food labelling** to support public awareness.

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IMAGE: DANIEL BURKA / UNSPLASH.COM

ADDRESSING RISK IN CONDITIONS OF UNCERTAINTY, IGNORANCE, AND PARTIAL KNOWLEDGE

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INTRODUCTION

Important decisions must often be made despite uncertainties, ignorance and partial knowledge. Individuals and organisations tasked with making policy, designing emergency responses and other decisions involving risk and uncertainty ('decision-makers') may choose an action having considered possible outcomes, their chances of occurring, and their consequences. However, the influence of scientific uncertainty in decision-making is often unclear. Here we consider how scientists might more effectively contribute to the decision-making process under conditions where scientific uncertainty is present.

Our group brought together 15 early- and mid-career researchers from diverse disciplines: statistics, applied mathematics, astrophysics, epidemiology, earth and agricultural science, numerical modelling, psychology and cognitive neuroscience, engineering, and oceanography. Our collective experience in addressing uncertainties, ignorance and partial knowledge in the risk context is diverse and extensive. The modelling and analytical techniques used by members of our group are as diverse as our areas of expertise.

Our diverse disciplinary perspectives meant that core terms (e.g. *model*, *uncertainty*, *stakeholder*, and *decision-maker*) were understood differently by individuals in the group. To address this we designed a framework to make hidden knowledge and assumptions explicit in our discussions (illustrated in Figure 1). We propose that frameworks such as this be used to increase transparency between different disciplinary perspectives when communicating about risk and uncertainty.

A particularly important aspect of this framework concerns the identification of **need** at the beginning of the process, and **feedback** at the end. It is essential that scientists contributing expert advice derived from models explicitly state the motivations that underlie their modelling process from the outset. Decision-makers should also provide feedback to the science community as to how scientific advice informed the decision-making process. If scientific models were not used in the decision-making process, was this because other pressures intervened? Or perhaps the model itself was not easy for decision makers to understand and a modification is required to increase transparency.

In addition to the problems associated with discussing core modelling concepts across different disciplines, publicly communicating risk that is constrained or limited by scientific uncertainties, ignorance and partial knowledge is fraught with its own challenges. Our group scrutinised the processes by which risk is communicated, and then defined and addressed challenging contemporary questions in risk communication.

No one specific approach is likely to be ubiquitously applicable when explaining the different types of uncertainties and risks associated with a system to the general public. However, we present here recommendations for best practice communication of risks and uncertainties in various scenarios, as well as defining avenues for future research.

RECOMMENDATIONS

Develop a better understanding of how uncertainty affects decision-making

More empirical evidence is needed, including documented case studies, on how scientific uncertainties contribute to the decision-making process. It is unclear whether decision-makers consider scientific uncertainty within the diverse collection of utility functions and theories that might influence the decision-making process, and if so, how? It may be unethical for scientists to deliberately exclude uncertainties in scientific communications with decision-makers. However, communications that emphasise uncertainty may influence the perceived credibility and value of the associated science within the decision-making framework in unpredictable ways.

To achieve this we call for **contributions from both scientists and decision-makers that describe how scientific uncertainty of all forms is considered within decision-making scenarios**. For example, do higher levels of uncertainty in bushfire trajectory or tsunami wave height

Figure 1: A framework for making implicit assumptions explicit when modelling risk and uncertainty	
Need	Define the need for the approach. What is the core question that it seeks to answer?
Audience	Who uses the predictions of the approach? What are their needs and requirements? Are there conflicting perspectives?
Assumptions	What method does this approach use? (e.g. hierarchical Bayesian model, simulation, non-monotonic reasoning, fuzzy logic).
Input uncertainties	What uncertainties enter into the approach or model at the outset? Are they systemic? Perhaps they arise due to measurement?
Error propagation	How do errors and uncertainties propagate through the approach? Does the modelling process itself create uncertainty?
Output uncertainties	What uncertainties are output from the modelling process? What mathematical/computational form and structure do they take?
Risk calculation	How is risk calculated in this approach? What definition is used? Does it have any field specific peculiarities?
Communication	How is risk and uncertainty communicated? How well are these reports understood by decision-makers?
Issues	Does the approach have specific strengths and weaknesses? What issues does it have that should be made explicit for decision-makers?
Feedback	What decision was eventually made in the context of the need? Was it effective? Did it accord with the recommendations of the approach taken?

models influence evacuation and land planning policy decisions? Or does precautionary reasoning under high estimates of risk favour evacuation and more restrictive land use policies irrespective of model uncertainties? Where opposing scientific interpretations exist, do decision-makers preferentially favour science with lower levels of uncertainty, or science that supports precautionary measures? How is scientific information considered against other societal, economic and political factors that influence decision-making? Understanding how uncertainty is perceived and interpreted will enable scientists to more clearly communicate about data and enable decision-makers to base their decisions on quality information. We encourage submissions to open access peer reviewed journals and other outlets that provide detailed accounts, from both scientists and decision-makers, of how uncertainty was (or was not) considered in diverse decision-making scenarios.

In addition, a significant **interdisciplinary research priority should be placed on understanding how decision-makers, media, and the public respond to uncertainty in the dissemination of scientific research, including the trustworthiness of science, scientists and communicators**. This is a fruitful avenue for evaluating how scientists can most effectively contribute to both community-driven ('bottom up') and government-driven ('top-down') decision-making processes. This research could be supported by establishing networks for fostering interdisciplinary research.

Such networks should include decision-makers and scientists, and should aim to improve the interpretative scientific skills of decision-makers and the communication skills of the scientific community. Decision-makers will be better placed to make evidence-based decisions if they are directly involved in the design of scientific models with outputs targeted towards their needs. More interdisciplinary meetings and workshops should be held in a bid to facilitate the creation of these networks of interaction between scientists and decision-makers. We suggest that the Australian Council of Learned Academies would be ideally placed to facilitate the creation of these networks and identify priority questions that will encourage interaction. More focus upon cross-sectoral drivers is also encouraged. While the Australian Government's Science and Research Priorities mention risk for specific topics of interest, we believe that a broad and systemic approach to understanding how risk and uncertainty influence decision-making irrespective of their domain of application is needed. It will be important for all parties to be able to maintain their independence and avoid conflicts of interest within this framework.

Finally, it is essential that **decision-makers are provided with training to recognise the conventions and inherent frailties of their scientific advisors**. Just like all humans, both scientists and decision-makers are subject to problems including bias, cognitive fallacies, the misinterpretation of correlations, and the exclusion of important sample size effects. It is beneficial to society to have decision-makers who can interpret, scrutinise and prioritise scientific

evidence, particularly in instances where consensus does not exist.

Facilitate improved communication of risk and uncertainty between scientists, decision-makers and the general public

A common lexicon amongst scientists would be a valuable asset to adopt to facilitate effective communication between scientists and decision-makers. **A set of guidelines for reporting risk and uncertainty** could be co-created in these networks with an aim of reaching a common language that can be understood by all, irrespective of their background. Concepts such as error codes[1] could be investigated as a first step in this process, as they would allow for a standard vocabulary to be used across disciplines and make communication transparent regardless of which discipline the model arose from. Figure 1 should only be thought of as a first step in this direction.

Similarly, **methods for clearly communicating whether there is any value in supplying more information to decision-makers are required**. While some risks arise from uncertainty that might be reduced with more research, the utility of doing so is also important to consider. For example, we are uncertain precisely how climate change will affect Australian cities, but know enough to be sure that decision-makers would be unwise to delay action until more information is obtained. However, as decision-makers are held accountable for the decisions that they make, it is essential that they have access to tools for exploring whether additional models and scientific information can actually improve the likely outcomes of a decision, or not. Proper networks of interaction will facilitate the design and delivery of such tools. In addition, these networks will provide decision-makers with ways in which they can both communicate and justify their chosen course of action to the public, including the uncertainties inherent in taking such an action.

The communication pathways by which scientists might report to decision-makers are not always clearly defined. High-profile individuals or organisations are typically selected to present science evidence directly to decision-makers or to science advisory panels, but the processes by which these experts are selected, and the mechanisms by which other scientists might contribute relevant science including uncertainties to decision-making, can be unclear. Sometimes important new scientific knowledge has been obtained, but no clear pathway for taking it to a decision-maker is evident. **Direct and open communication between scientific experts and decision-makers is required and can be achieved via explicit and standardised pathways**. Existing systems to provide these pathways, such as public consultations, can be more extensively applied. In addition, relevant organisations such as the Australian Council of Learned Academies can develop interdisciplinary science advisory panels that can provide a first port of call for other scientists, decision-makers and the media. Panels should include topic specialists, data specialists, communication experts and decision-makers. Emphasis should be placed on science inclusiveness and quality, development of communication strategies, and relationship building between scientists and decision-makers. The inclusion of locally-based scientific experts on advisory panels when evaluating risk decisions with a geographic and/or cultural element (e.g. earthquakes, drought and agricultural pests) should be viewed as beneficial. It is also essential that alternative pathways are explicitly defined to allow additional scientists to contribute relevant science.

Finally, we recommend **communication training for scientists who communicate scientific messages that include uncertainty to the media and public**. This should be evidence-based training which incorporates communication techniques and imparts an understanding of how uncertainty contributes to personal decision-making in risky situations.

1 Error codes are enumerated messages often used to indicate faults in computer software. They could be used to specify where risk and uncertainty arises in the science (e.g. inputs, model, numerical).

IMAGE: STUART-PHOTOGRAPHY / PIXABAY.COM

RISK AND RESOURCE ALLOCATION IN THE ENVIRONMENT

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INTRODUCTION

Environmental problems include some of the greatest challenges facing Australia. Climate change, pollution, land clearing and degradation, invasive species and biodiversity loss already impact our economy and society, and will increasingly do so in the coming decades as our need for resources expands. Addressing these problems requires accurate tools for measuring the relative economic and environmental costs and benefits of proposed projects that impact the environment. However, existing approaches to assess the relative benefits and costs of projects often fail to adequately capture uncertain environmental impacts, and many projects are left exposed to significant environmental risks. If these risks are realised, projects may cause environmental harm under a pretence of economic growth that actually results in a net loss to society and the environment. Given these problems, it is essential that we develop a transparent, reliable and interdisciplinary means of evaluating the true worth of environmental projects if we are to balance economic growth with preserving a healthy environment for future generations.

Cost-benefit analysis

The dominant tool used to assess and prioritise potential projects in economics and public policy is cost-benefit analysis (CBA). The theory is that CBA quantifies the expected monetary benefits and costs of a project, with resources then being allocated, in a resource-limited environment, to those projects with the highest benefit-to-cost ratios. However, CBA has known problems when applied to environmental issues. For example, the costs and benefits of an environmental outcome that will be achieved many decades into the future are often undervalued. Another example is that many environmental projects include significant non-market values such as the intrinsic value of species, meaning that traditional market valuation tools are not reliable.

Much has been written on the issues associated with the use of CBA in environmental projects, and we do not attempt to cover all these issues in this report. Rather, this report focuses on four areas where simple reforms to best practice will significantly improve the efficient use of CBA in Australia.

RECOMMENDATIONS

Increase transparency and accountability by requiring mandatory publication of all CBA models used in decision-making for publicly funded environmental projects

Environmental benefits are notoriously hard to quantify, because most environmental goods and services have no obvious market and aim to deliver long-term benefits that are hard to value appropriately in the present. Compounding these issues are the inherent uncertainties about outcomes in natural systems and difficulties in accounting for the risk of irreversible change, such as species extinctions. As a result of these challenges, there are many ways to define benefits and costs in environmental projects. The methods and assumptions used can strongly influence the calculated cost-benefit ratio that is used in decision-making and can therefore bias whether or not a project is implemented. Although CBA helps to determine resource allocation and public policy, the models and assumptions used are rarely published or publicly available so it is impossible to determine their validity. The lack of transparent assumptions and methods can lead to widely differing estimates of project viability which cannot be easily reconciled or evaluated unless the underlying data, methods used and assumptions are made available. For publicly-funded projects that are assessed using a CBA, we recommend that local, state and federal governments require that the CBAs be made publicly available as part of the approvals process. Both the models used and their associated data should be made available.

CBA is only one input into most decision-making processes, yet its relative importance and how it coordinates with other factors is often poorly explained. Published CBA reports should also contain a short statement by the approving authority stating how the CBA outcomes were used in the decision-making process.

Develop national cost-benefit analysis guidelines for environmental projects, as best practice standards for CBA

Significant benefits could be achieved by establishing cost-benefit analysis guidelines for environmental projects[1] to be used in CBA assessments for publicly funded

1 It is envisaged that this would be similar to the Better Regulation Guideline (http://www.cuttingredtape.gov.au/handbook/australian-government-guide-regulation) which is already widely used in government policy making.

environmental projects in Australia. These guidelines should encourage the publication of CBA models, including the transparent disclosure of methods and assumptions. Controversial decisions such as the relative values of present and future benefits must be fully documented and explained in a way that is comprehensible to both policymakers and lay readers. The guidelines would be created by decision-making or approval bodies in consultation with practitioners, regulators and academics from multiple disciplines including economics. The guidelines would benefit decision-makers and stakeholders by better framing and informing areas of agreement and contention, improving the accountability of project proponents and encouraging the use of best practice methods for cost and benefit estimation.

Proponents should be encouraged by decision-makers to publish their CBA models according to the guidelines. Published CBA documents should contain a statement of how the CBA complies with the guidelines; this statement would allow proponents to claim best practice certification. The publication of CBA models, and the ability to test those models using data derived after the commencement of the funded project, would encourage learning from mistakes and drive innovation in improved benefit estimation techniques. For proponents, better CBA techniques arising from open reporting would lead to more certainty about outcomes that would reduce and better measure project risks, while the ability to demonstrate compliance with an accepted best practice standard could reduce red tape, improve the social licence to operate and increase public trust in environmental projects.

While the default should always be transparency from the outset of the project, we recognise that some projects may contain highly commercially sensitive data and thus may not be able to publish all CBA data at the inception of a project. For these projects, short-term embargoes of 12 months to five years could be used. However, embargoes should only be used where the data are not already in the public domain and are highly commercially sensitive. Any embargo should be limited to the earlier of the date that the data enters the public domain through lawful means or the date the data becomes out of date (i.e. is no longer commercially valuable).

The adoption of cost-benefit analysis guidelines for environmental projects is not without precedent. In 2011, the Norwegian Government appointed an expert committee to review the cost-benefit analysis framework used in the analysis of public measures. The report published in the Official Norwegian Reports NOU 2012:16[2] contained 50 recommendations to improve the use of CBA on Norwegian public projects, including five specifically on the use of CBA in environmental projects. The adoption of such an approach recognises that when taxpayer funds are spent on publicly funded projects, best practice CBA should be used to ensure that money is used efficiently and that the policy analysts and proponents should be publicly accountable. This can only be evaluated if the criteria behind project selection decisions are explicit and transparent.

National and international principles and guidelines on risk management, such as ISO 31000:2009, emphasise the importance of transparency and a process that is iterative, responsive to change and facilitates continued improvement. These standards should apply to the use of CBA in Australia.

Fund a study to simplify and implement existing tools to deal with sequential decision making

Uncertainty is inherent in environmental projects and influences the outcomes of CBA. Quantifying the benefits of environmental projects is difficult due the inherent complexity of ecological systems, limited understanding of ecological processes and how benefits will manifest, and the long, inter-generational time frames before benefits are typically realised.

Environmental systems are subject to many interacting external forces that may be predictable in the short term but become harder to foresee over long time periods, including natural variations (e.g. drought, wildfire or other natural disasters, or the spread of weeds and invasive species), human impacts (e.g. development proposals in the project area or oil spills), and ecological responses to environmental change. Each of these external events influences the risk of project benefits not being realised. As CBA is commonly only conducted once before the project is commenced, the analysis is conducted on the assumption that decisions only need to be made once, whereas in reality projects are comprised of a series of sequential decisions, often corresponding to project milestones.

By making a single decision at a snapshot in time, there is no chance to review CBA predictions in light of current conditions and new knowledge and revise the expected project benefits. Tools for sequential decision making (such as stochastic dynamic programming, real options analysis and dynamic Bayesian networks) are used in academia and could be simplified for use in practical applications of CBA. We recommend that an academic study (in collaboration with practitioners and decision-makers) is funded to simplify existing tools and incorporate them into the proposed guidelines for use by practitioners.

Account appropriately for non-monetary future benefits

Some environmental benefits are hard to quantify in monetary terms. Values such as the intrinsic value of species, the value of green space and clean air are difficult to price because they involve value judgements made by society. Even where the benefits are relatively well defined,

2 https://www.regjeringen.no/contentassets/5fce956d51364811b8547eebdbcde52c/en-gb/pdfs/nou201220120016000en_pdfs.pdf

the long time frames that must be realised before benefits are received causes problems in economic models due to discounting of future benefits. In standard economic models, future benefits are worth less than benefits received today. The rationale for this is that money received today could be invested and could collect interest, so a dollar received today would be worth more than a dollar that will be received in the future. This is straightforward when comparing strictly financial investments, but may be inappropriate when the benefits received are not only monetary. There is no agreement on whether an environmental benefit (e.g. cleaner air) is worth more today than in the future.

In addition, reducing the value of the future means that every project has a lifetime, beyond which accrued benefits are essentially zero. Where there are long delays in the realisation of environmental benefits, inappropriate discount rates can result in environmental benefits not being included in CBA calculations. All CBAs should specify how future benefits are valued and incorporated in a transparent way that can be interpreted by a lay reader. For example, rather than only reporting the discount rate, which is difficult to interpret, CBA proposals should state the number of years for which benefits are included (i.e. the number of years until discounting makes benefits negligible).

IMAGE: SILVER BLUE / FLICKR.COM (CC BY-SA 2.0)

RISK IN INTERNATIONAL SECURITY

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INTRODUCTION

International security encompasses diverse systems, including inter-state cooperation through the United Nations (UN), targeted alliances between nation states, partnerships between nation states and global corporate bodies, and issue-specific international legal regimes. International security today must be understood far more broadly than merely the presence or absence of armed conflict between nation states—it encompasses concern for human, resource and environmental securities in complex environments. In their development of security strategies, nation states and other international actors seek to mitigate or respond to risks which threaten human and societal survival and peace. The ways in which various actors and practices produce and respond to risk in complex environments is affected by a high degree of uncertainty.

Our group comprised interdisciplinary scholars who collectively engaged with meta-problems in international security, including the meaning of sovereignty in a globalised era, the effectiveness of global governance and the need for accountability from international decision-makers. Collaboration among group members identified **disruptive technologies**, **global migration flows** and **human induced environmental changes** as key risk areas in international security that warrant concentrated examination in a global level. These are three salient fields of risk that must be grappled with—the risks posed in each field may be uncertain but they are potentially imminent and catastrophic, generating consequences to multiple actors in our current global organisation.

Conflict is not one of the risk areas we addressed specifically as we consider it to be central across all international security concerns. A key focus for this group was consideration of how the risks posed by disruptive technologies, global migration flows and environmental changes could generate different forms of conflict. For example, territory loss due to climate change impacts may drive competition for reduced resources and produce or heighten conflict. Uncertain capacities within disruptive technologies such as the Internet of Things (IoT) or artificial intelligence (AI) could trigger cyber conflicts that have real-world international security implications.

Australia took a leading role in the establishment of the United Nations following World War II, however today—along with its allies—Australia faces multiple challenges in the approach to key international security risks. Through the following recommendations, we indicate concrete means by which Australia can renew its leadership in the 21st century.

We believe that Australia can be more ambitious and demonstrate global leadership through local and national innovation in the area of disruptive technology, in preparation for global migration flows, and in mitigating and adapting for environmental change. We recommend parallel research and policy agendas in these three areas.

RECOMMENDATIONS

Disruptive technologies

Australia must be proactive and ambitious in its approach to disruptive technologies. There is great uncertainty regarding the opportunities and risks associated with disruptive technologies (including but not limited to robotics and artificial intelligence, biotechnology, nanomaterials, 3D printing, advanced energy storage and generation, and quantum computing). The uncharted development of future technologies (e.g. IoT, AI) and the use of existing technologies in unanticipated ways presents opportunities that Australia cannot afford to miss. Downside risks (e.g. economic adjustment or disruption of technology-dependent infrastructure) will need to be managed carefully. Such risks could arise from changes such as the impact of automation on workers or increasing inequality, as noted previously by the Productivity Commission[1].

Technology holds significant promise and in some cases an irresistible lure for human societies, with potential to support increased productivity and quality of life. Much of the world's population now depends to varying extents on highly complex technological systems and while these systems continue to transform quality of life, they also have the potential for negative and unanticipated consequences. Australia can take a proactive and ambitious stance towards the regulation of disruptive technologies by seeking to understand both benefits and potential risks, such as whether:

- cyber-conflict could transform and extend the scope of armed conflict

1 http://www.pc.gov.au/research/completed/digital-disruption#introduction

- radicalisation via social media could be effectively countered by de-radicalisation policies
- increased automation could displace workers and widen inequalities
- automated modes of transport could fail or present unexpected behaviour.

Create an effective policy–research collaboration to respond to disruptive technologies

Interdisciplinary research is critical to creating policy settings that allow us to capture the potential benefits of new technologies and mitigate their risks. To promote impactful interdisciplinary research and policy, we recommend that the Australian Government:

1. build structures that facilitate the work of interdisciplinary research teams to investigate the implications of new technologies. Such structures should have scope to set or respond to priorities in an independent, non-partisan manner
2. empower such structures to identify research priorities and direct research and policy development funding towards them
3. enable policy setters and researchers to keep up with fast-paced technological change and the need for timely and effective regulation of disruptive technologies through annual policy and research review across key priority areas.

Global migration flows

Australia must focus on the human and resource security implications of global migration flows. There are myriad intersectional security risks posed by current and future global migration flows, whether these result from conflict, persecution, climate change impacts, economic drivers or other factors. These population movements can potentially disrupt national or regional identities, and can have huge impacts on resource availability and standards of living. Crucially, these movements encompass some of the world's most vulnerable people, whose experiences are rarely centralised in policy debates regarding their treatment.

The polarisation of perspectives across nations and regions in response to unprecedented migration flows results in emotive rather than evidence-based responses that are unlikely to be effective or successful. Suggestions that migrants are inherently threatening to international or national security are not based on scientific or historical evidence and result in conflict and discrimination within and across nations: a situation that can lead to further polarisation.

There is a growing trend for nations to rely on securitisation[2] strategies in response to global migration flows. Such approaches risk the marginalisation of broader security concerns, particularly human security and resource security.

Realign Australian law, policy and practice with international legal obligations, and adopt a position of global leadership by developing and implementing evidence-based policy

The Australian Government could reduce the risks posed by marginalisation and conflict by:

1. implementing evidence-based policy with respect to the significant and adverse human impact of mandatory and indefinite detention of asylum seekers arriving by boat, in a way that brings domestic law, policy and practice in relation to asylum seekers and refugees into line with international legal obligations
2. taking up a position of leadership in negotiations for effective regional responses to human migration flows. Adopting the first recommendation will enable Australia to do this in good faith.
3. undertaking national interdisciplinary research into how migrants and destination communities can effectively manage rapid or unplanned change. This will enable the social implications and lived experience of inclusion in the short and long term from the perspective of all stakeholders to be a part of the equation when developing policy related to international security
4. adopting whole-of-government policies that mirror best practice efforts to integrate the needs of migrant populations and the resource implications for destination communities.

Environmental change

Australia must respond proactively to the international security implications of environmental change. Multiple risks are associated with the consequences of environmental change, including changes to the climate system and in other systems critical to Australian society. Important and immediate questions arise for Australia including: How will Australia adapt to rapid changes in food production capacity at home and within our region? How will we support our Pacific Island and Asian neighbours as their territories become less habitable?

National and international security implications of environmental change will not wait for Australian society to accept the science of environmental change. Noting that there is no credible debate around the science of climate change, governments of all levels in Australia need to adopt evidence-based, proactive adaptation and risk mitigation strategies.

2 Securitisation is the transforming of subjects into matters of security, when those matters could be validly characterised in other ways.

Institute stable governance structures to address environmental change

High-quality and widely accepted scientific research has comprehensively identified the consequences of the risks posed by climate change. In that context, we recommend actions that address the primary impediments to Australia's efforts to address those risks should include:

1. ensuring rigorous and stable national governance arrangements regarding scientific advice on climate change and adaptation policy
2. developing a national science communication strategy that educates the Australian community on the urgent risks posed by environmental change and how we can all be proactive in attending to these
3. adopting the precautionary principle to guide Australian policy responses to uncertain but scientifically plausible risks. This principle requires action to avoid or diminish the risk of harm to humans and the environment.

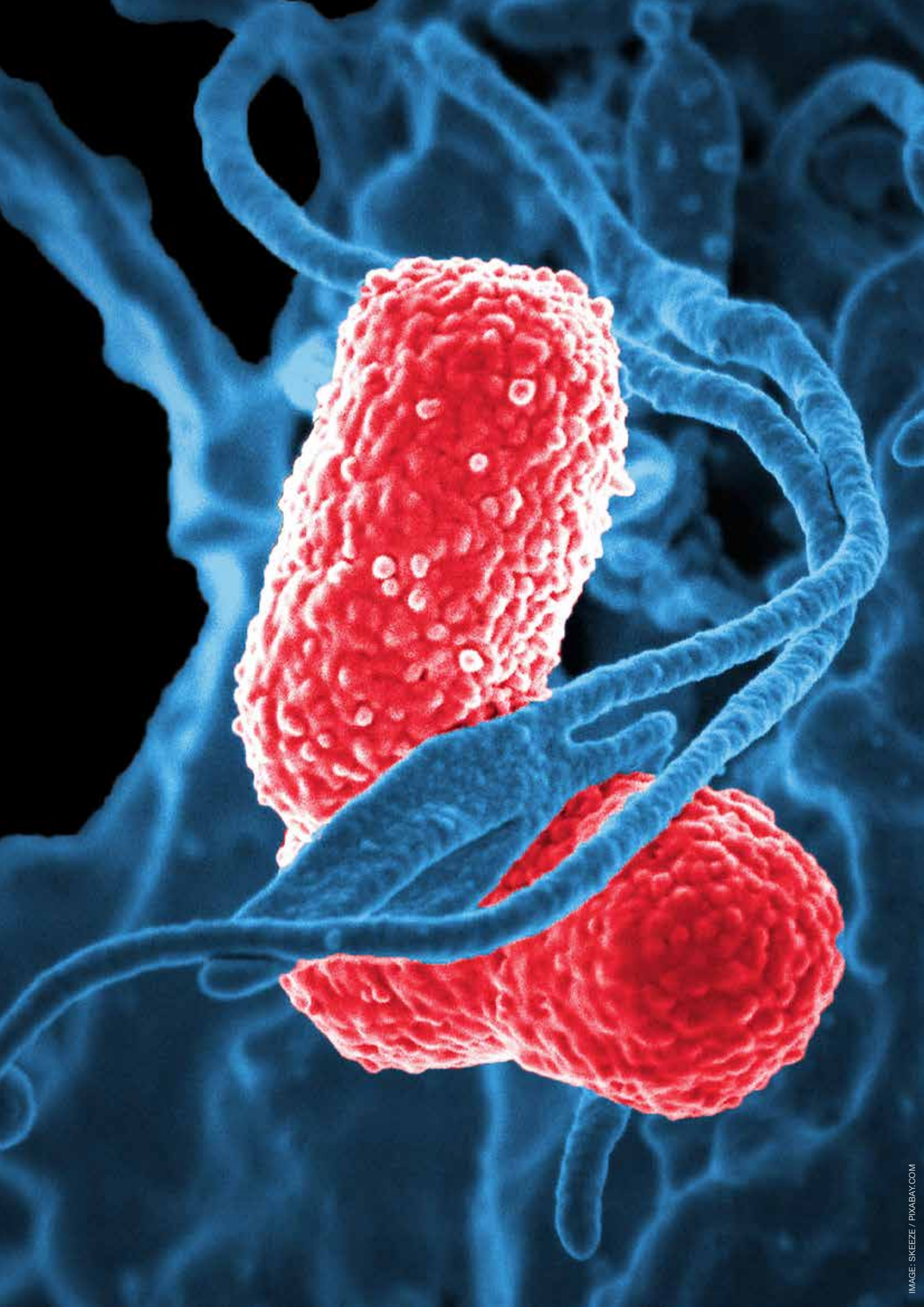

IMAGE: SKEEZE / PIXABAY.COM

ANTIMICROBIAL RESISTANCE: A COMPLEX MULTI-FACTORIAL PROBLEM REQUIRING AN ORCHESTRATED INTERDISCIPLINARY RESPONSE

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INTRODUCTION

'By 2050, 10 million lives a year and a cumulative 100 trillion USD of economic output are at risk due to the rise of drug resistant infections…'[1] These are sobering projections from the recently published Review on Antimicrobial Resistance chaired by the economist Jim O'Neill, adding another compelling voice to similar reports from the Australian Government[2] and the World Health Organization[3]. The cumulative message is clear and unequivocal: the global risk of antimicrobial resistance (AMR) is real and potentially catastrophic.

Antimicrobials are drugs that treat infections caused by microorganisms. AMR arises when microorganisms evolve to survive exposure to antimicrobials. This is inherently linked with all antimicrobial use, but especially to increasing and poorly managed antimicrobial use. The rise in AMR threatens not only infectious disease management but also routine contemporary medical procedures such as orthopaedic and obstetric care, chemotherapy and organ transplantation. Moreover, as a result of agricultural use and environmental contamination, AMR also endangers food and water security.

The drivers of AMR are multifaceted and interconnected. Significant drivers of AMR stem directly from human action and behaviour across the health, agriculture and environmental sectors, namely: the use and misuse of antimicrobials, exacerbated by inadequate governance and fragmented and siloed regulation around antimicrobial use, and a lack of awareness of the risks of AMR and/or capacity to act among many stakeholders. The impacts of these drivers are set to increase as a consequence of population growth, mobility and demographics (increasing demand for antimicrobials in food production and health), whilst the contribution of environmental contamination with AMR microorganisms and residual antimicrobials is only starting to become apparent. AMR is a complex policy problem and also a 'wicked problem' such that no single action in any single sector will be sufficient and any action will have unavoidable negative outcomes for one or more stakeholders. For these reasons, coordinated, collaborative and cross-sector action is essential, but as a largely human-made problem, it is within our power to intervene, at both the local and global levels.

Accordingly AMR must be treated as a 'One Health' problem that straddles the interface of humans, animals, and their environments (Figure 2). As a working group our diversity of expertise—which includes ethics, law, veterinary science, microbiology, pharmacy, social and political science as well as expertise in food security, environmental chemistry and agriculture—positions us perfectly to evaluate complex interdisciplinary resolutions to this problem.

Framing AMR in terms of risk can emphasise its One Health relevance

AMR can be considered a quantifiable problem: with appropriate resources the level of resistance in microorganisms can be measured and this can be used to estimate the future impact on morbidity, mortality and the economy. However it is also essential to consider the societal perception and cultural changes which impact on the understanding and processing of risk and uncertainties relating to AMR. Considering these two components together we are better able to capture how AMR is communicated to and perceived by stakeholders, and how it ranks amongst other risks or immediate needs.

Given the projected impact of unrestrained AMR it is important for multiple stakeholders (e.g. the general public, food producers and human and animal health practitioners) to actively participate in behavioural change. Yet, despite the seriousness of the risk of AMR, this is not occurring at the

1 Wellcome Trust & UK Government (2016). *The Review on Antimicrobial Resistance—Tackling Drug-Resistant Infections Globally: Final Report and Recommendations*. London.

2 Australian Commonwealth Government (2015). *Responding to the threat of antimicrobial resistance. Australia's First National Antimicrobial Resistance Strategy 2015–2019*. Canberra.

3 World Health Organization (2015). *Global Action Plan on Antimicrobial Resistance*. Geneva.

Figure 2: Antimicrobial resistance is a One Health problem with multiple drivers. Diverse stakeholders exert influence over antimicrobial use in the One Health context

required rate. For some stakeholders, this is due to a lack of awareness but for others, barriers that dissuade behavioural change such as social expectations, complacency or economic disincentives play an important role. Identification of these barriers, as well as facilitators of behavioural change, is necessary to guide policy and regulation. Importantly such initiatives must be married with clear communication with all stakeholders in the One Health framework such that the role of stakeholders in the problem and its solutions are clear and that a consistent and coordinated response is elicited.

Current discourse on tackling AMR

Multiple governments and health organisations have issued recent reports detailing the following strategies for responding to AMR:

1. reduce the use of current antimicrobials in order to extend their medical efficacy
2. develop new antimicrobials to replace ineffective ones,
3. prevent and reduce infections to negate the use of antimicrobials
4. improve surveillance of antimicrobial usage and resistant infections to guide prudent use of antimicrobials
5. improve public awareness and education regarding AMR to reduce antimicrobial demand.

Within this context, we sought tangible steps to accelerate one or more of these objectives and to address additional areas of importance that have been so far overlooked. Just as an Australian, Howard Florey, pioneered the first clinical use of penicillin, Australia can once again lead in health, environment and food security, by spearheading interdisciplinary solutions to AMR. By adopting a position of global leadership, Australia stands to reap enormous local economic and healthcare benefits whilst driving delivery of a global public good.

RECOMMENDATIONS

Facilitate interdisciplinary research in AMR through targeted funding calls

Managing AMR requires interdisciplinary collaborative research. However there are barriers to funding interdisciplinary research in Australia: medical and non-medical research is explicitly separated by the structure of the major federal funding agencies (the National Health and Medical Research Council and the Australian Research

Council). Further, recent research reports that the greater the degree of interdisciplinarity of an ARC Discovery Projects grant application, the lower the probability of it being funded[4]. We recommend that funds be reserved by relevant funding bodies (e.g. ARC, NHMRC and the newly established Medical Research Future Fund) for interdisciplinary One Health research on AMR that crosses traditional funding boundaries, and that they draw inspiration from the approach taken by funding bodies such as the UK Wellcome Trust. These funding bodies recognise the importance of combining a range of different perspectives to address significant (public) health challenges by actively encouraging and funding interdisciplinary collaborations between researchers in the social and biomedical sciences.

In recognition that new antimicrobials are a short-term solution to AMR that will require a continuous development pipeline into the future, specific research priorities should be targeted to novel anti-infective strategies; adaptive therapies and diagnostic tools (e.g. bacteriophage therapy, nanotechnology, immunodulatory compounds, gene editing-based technologies and rapid point-of-care diagnostics); and developing improved health informative tools (including genomic surveillance) for enhancing linkages of existing surveillance systems in human medicine, veterinary practice, agriculture, aquaculture and the environment. These initiatives will help reduce demand for antimicrobials and support evidence-based decision-making when designing and evaluating antimicrobial stewardship programs.

Evaluate the impact of antimicrobials and resistance gene reservoirs in the wider environment

Environmental 'hotspots' of AMR are suspected to play a major but largely unexplored role in the AMR challenge. AMR microorganisms and their genes are present and persistent in major environmental waste streams such as municipal wastewater (mixed household, hospital, industrial and commercial wastewater) and agricultural wastes (effluents, composts and processing residues). Antimicrobial residues are also present in these systems because they are only semi-metabolised in their human/animal recipients and incompletely removed in conventional waste treatment processes. A genetic link between AMR and pollutant-associated genes for other chemical pollutants (e.g. heavy metal resistance) results in a complex interplay of selection and co-selection of AMR microorganisms in polluted environments that may increase the risk of transfer into human environments through direct contact or the food chain.

Much remains to be understood about how environmental pollution drives the emergence of resistant organisms in the environment, and how these environmental reservoirs of resistance impact on food and water security and the clinical efficacy of antimicrobials. This is a major knowledge gap in our understanding of AMR in the One Health context. Therefore, we recommend that addressing this gap be explicitly listed as a Priority Area for Action in Objective 5 (Agreeing a national research agenda) of Australia's First National Antimicrobial Resistance Strategy 2015–2019[5]. Data from this research must be used to inform risk analyses and guide processes for waste management, reuse and recycling as part of Objective 4 (Prevention and control of resistance) of the strategy.

Integrate socio-cultural and behavioural research into the development, implementation and evaluation of AMR management

A major aspect of successful AMR management lies in behavioural change but the diversity of stakeholders involved in AMR poses a significant challenge to the development and implementation of effective policy. We support the formation of collaborations between cross-disciplinary researchers and critical stakeholders (e.g. the Department of Agriculture, the Australian Medical Association, Australian Institute of Health and Welfare, and patient and community groups) to quantify and qualify the contribution, influence, understanding and perception of AMR. This will necessitate the formation, in close collaboration with the Council of Australian Governments (COAG), of a national government lead agency to coordinate and guide the efforts of all relevant groups federally and at a state level. This proposal is in line with recommendations from the National Antimicrobial Resistance Forum (November 2015) for creation of a 'supra-departmental' body to oversee implementation of the National AMR strategy[6]. Identifying facilitators and barriers to behavioural change in key One Health stakeholders can be used to develop 'bottom-up' education campaigns and change from within stakeholder groups as well as guide 'top-down' evidence-based regulation.

Incorporate antimicrobial use in food labelling to support public awareness

To ensure prudent use of existing and future antimicrobials, we recommend that regulation be expanded across all prescribers (e.g. health practitioners, veterinarians, dentists and in agriculture) to enforce reduction in antimicrobial usage. To encourage successful implementation, this expanded regulation should be informed by socio-cultural and behavioural research (refer to previous recommendation) and be designed in consultation with affected stakeholders. We also recommend labelling of raw and processed foods

4 Bromham L, Dinnage R & Hua X (2016). 'Interdisciplinary research has consistently lower funding success'. *Nature* 534:684–687

5 Australian Commonwealth Government (2015). *Responding to the threat of antimicrobial resistance. Australia's First National Antimicrobial Resistance Strategy 2015–2019*. Canberra.

6 http://www.health.gov.au/internet/main/publishing.nsf/Content/1803C433C71415CACA257C8400121B1F/$File/National-Antimicrobial-Resistance-Forum.pdf

where antimicrobials have been administered for non-therapeutic purposes in their production. This would empower consumers to make informed decisions and enhance consumer awareness on the widespread use of antimicrobials beyond medicine and healthcare. This also has the potential to reduce overuse of antimicrobials, particularly in agriculture. To minimise resistance gene spread, AMR microorganisms should be reclassified as adulterants in foods (levels to be decided). Regulatory and food labelling changes should not disadvantage Australian industry, and the effect of making this a requirement for trade partners should be investigated.

ABOUT THE THEO MURPHY HIGH FLYERS THINK TANKS

The purpose of the Theo Murphy High Flyers Think Tank series is to bring together early and mid-career researchers from a broad range of relevant disciplines to engage in thinking about novel applications of existing science (including social science) and technology. They aim to examine issues of national significance and to identify gaps in knowledge that should be addressed. These events are a unique opportunity for career development and networking among the nation's next generation of research leaders and their institutions. Think Tanks are one of the premier events of the Academy's calendar and this is the 15th that the Academy has held.

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Previous Think Tanks have culminated in reports to government that have been timely, well received and instrumental in influencing policy development (available at www.science.org.au/news-and-events/events/think-tanks).

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2010 Searching the deep earth: the future of Australian resource discovery and utilisation
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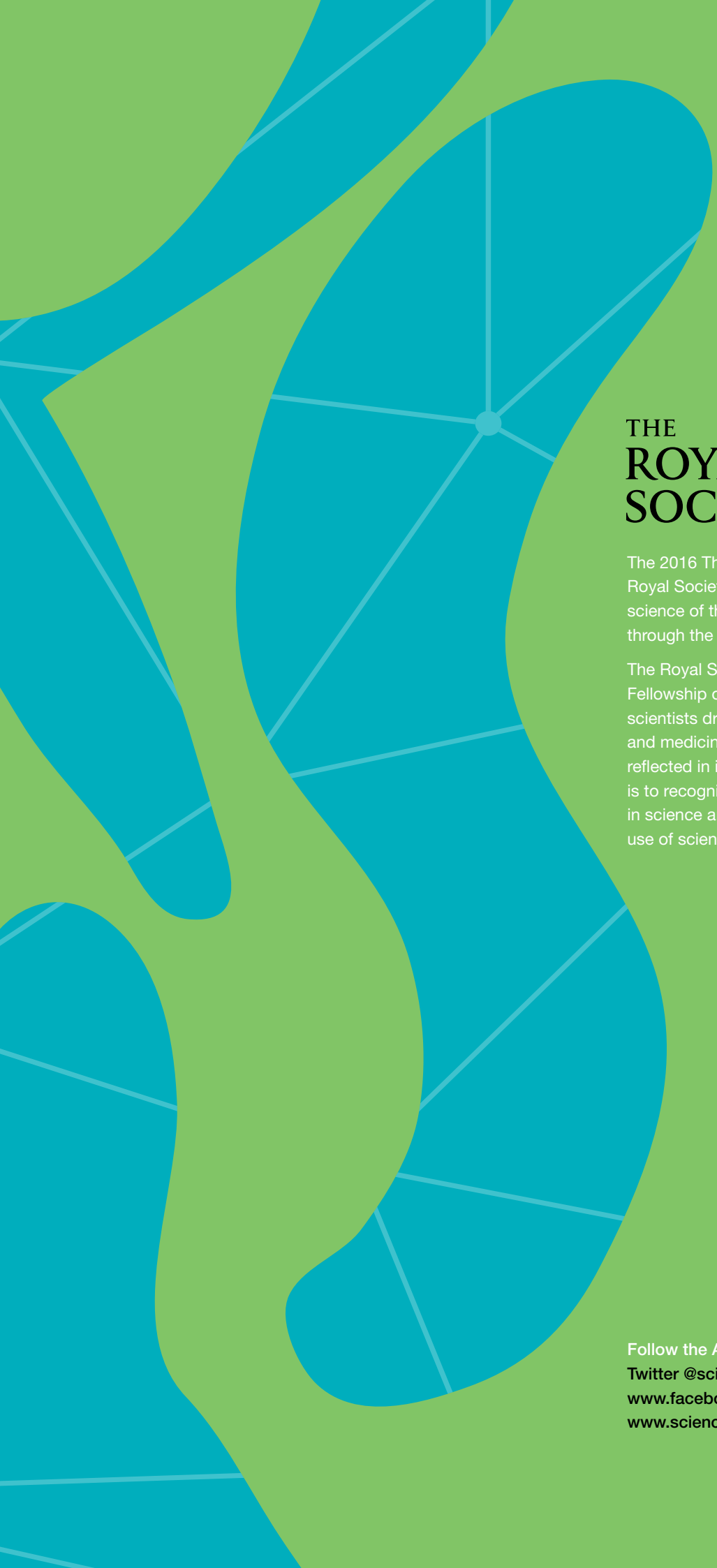
2012 Australia's population: shaping a vision for our future
2013 Inspiring smarter brain research in Australia
2014 Climate change challenges to health: risks and opportunities
2015 The stem cell revolution: lessons and imperatives for Australia



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